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THE DYNAMO

How Made and How Used

S. R. Bottone BY
S. R. BOTTONE

AUTHOR OF "ELECTRIC BELLS AND HOW TO MAKE THEM," "ELECTRIC
INSTRUMENT MAKING," ETC.

NINTH EDITION

WITH ADDITIONAL MATTER AND ILLUSTRATIONS

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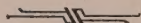
PREFACE.

THIS work was not written for the manufacturer of large Dynamos: it originally appeared in the pages of the *English Mechanic* in answer to the demands of many amateurs, who, desirous of constructing a small dynamo, capable of being worked by hand, and of giving a current sufficiently powerful for experimental purposes, were in need of such practical information, as to the correct proportion of the various parts, and the precautions necessary to ensure success, as they had been unable to gather elsewhere.

Encouraged by the flattering reception with which it has met, the author places it before the public in a separate form, trusting that it may lead many to taste the pleasures which can be extracted from even a slight acquaintance with the science of Electricity.

S. R. BOTTONE.

PREFACE TO THE SIXTH EDITION.



THE extraordinary demand which has arisen for this book, and the numerous private inquiries addressed to the Author, testify to the great interest taken in the subject of Dynamomaking by amateurs. For this edition the author has, while retaining all that was contained in the preceding, added about a dozen sections on the construction of the more modern types of machines, which he trusts will prove acceptable to those who may desire to construct larger Dynamos.

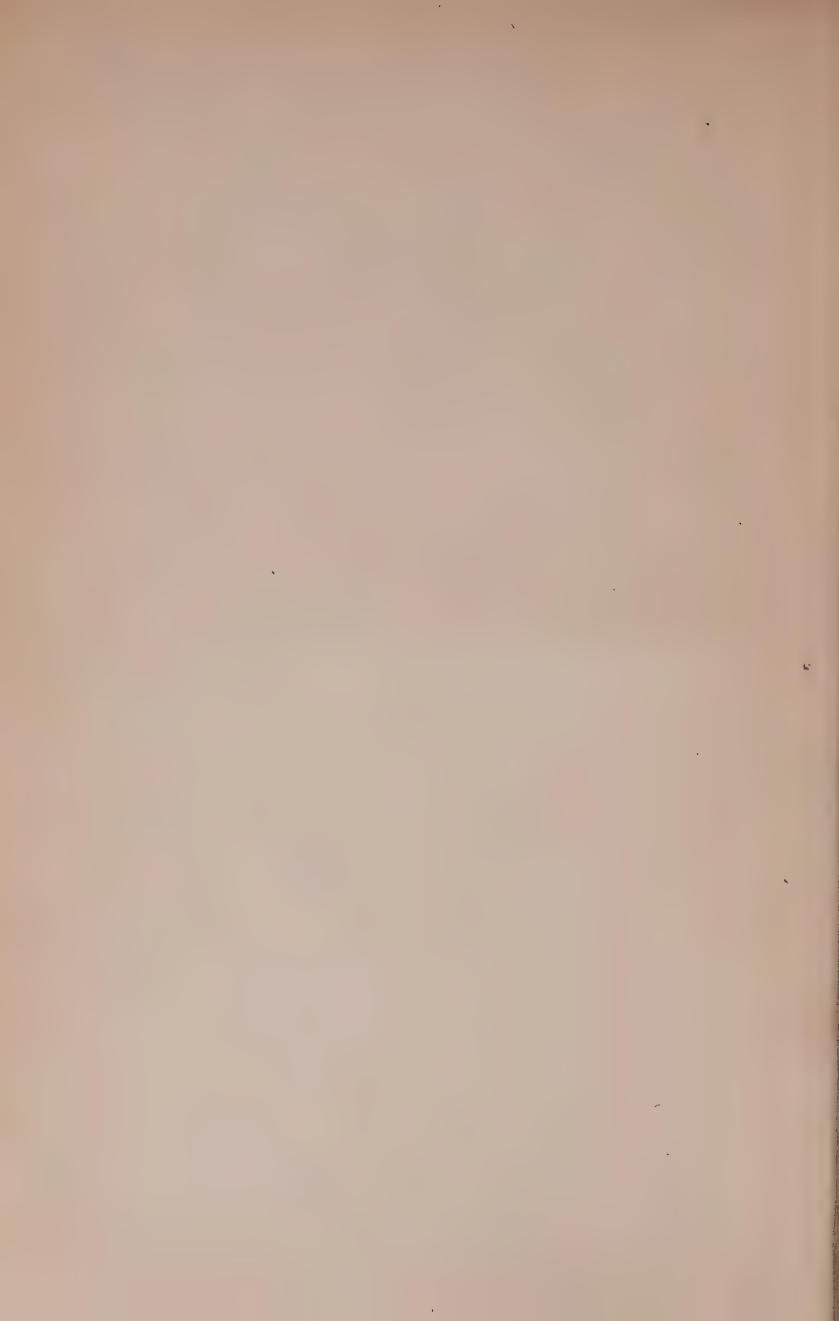
S. R. BOTTONE,
CARSHALTON.

PREFACE TO THE NINTH EDITION.

THE interest taken by amateurs in making dynamos has increased to an extraordinary extent. Hardly a day passes in which I do not receive letters asking for instruction in some branch connected therewith. To meet these requirements I have carefully revised and corrected the body of this work, and added some twenty sections, treating more particularly of the errors into which the would-be dynamo builder may fall, the avoidance of which are necessary to success.

S. BOTTONE.

CARSHALTON, *October*, 1895.



THE DYNAMO:

HOW MADE AND HOW USED.



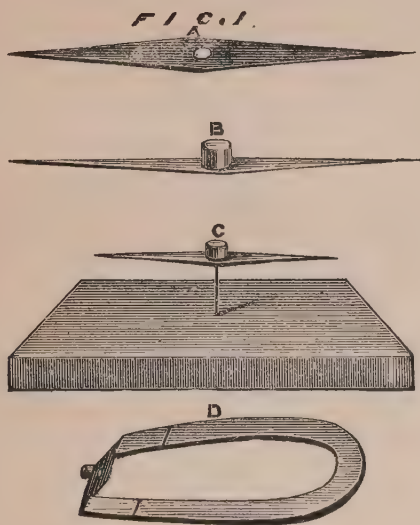
THE interest awakened in machines for the generation of current electricity, consequent upon the demand for electric lighting and transmission of power, has induced many amateurs to turn their energies to the construction of small dynamos, such as might replace a battery of eight or ten cells, without the disagreeable concomitants of changing acids, cleaning plates, etc., provided such dynamos could be afterwards worked without the employment of power. Such efforts have not generally met with success, owing to the fact that no work of a practical nature has yet appeared in which the construction of the dynamo is fully explained. When the principles which control the manufacture of such machines are understood, dynamos can be constructed with as much ease and certainty as induction coils; and in the following pages these principles will be elucidated sufficiently to enable the amateur to carry out his work in an intelligent manner.

§ 1. *What a Dynamo is.*—As understood at present, the dynamo-electric machine may be defined as a machine whereby energy (motion) is converted into electricity by the aid of the residual magnetism present in certain iron portions: which electricity is caused to react on the iron and so heighten its magnetism; and this increased magnetism in its turn gives rise to more powerful electrical effects, and so on, until a limit is reached, depending partly on the velocity of the motion, partly upon the relative apportionments of the size and quantity of the wire and iron

employed in its construction, and partly on the resistance throughout the circuit. Although this principle was fully understood, and described by Soren Hjorth, of Copenhagen, in his patents, dated October, 1854, and April, 1855, yet the name 'dynamo' (from *dynamis*, Gr., *force*) does not appear to have been used in this connection until Dr. Werner Siemens employed it in a communication to the Berlin Academy, January 17, 1867.

§ 2. *Faraday's Discovery*.—The closeness of the relationship between the phenomena which we call *electricity* and *magnetism* had struck many philosophers of the eighteenth century. Oersted, of Copenhagen, in 1819, was the first to prove, by a series of masterly experiments, the magnetic properties of current electricity; Ampère, and Arago in France, and Sir Humphry Davy in England, then distinguished themselves by their zeal and activity in this research; but the keystone of the arch was laid when Faraday, in November, 1831, showed that it was possible to call forth electric currents by means of a magnet. In order that the reader should have an intelligent knowledge of the principles which underlie the construction of the dynamo, it would be well for him to repeat some of the experiments about to be described, more especially as they are easy of performance and trifling in cost.

The first thing required will be a *galvanometer*, an instrument for indicating the presence of current electricity (and in some cases to measure its quantity). To make this, a piece of crinoline steel, 2 inches long and $\frac{1}{8}$ of an inch in width, is 'softened' by heating the middle portion over a gas jet or other flame, until red hot, then allowed to cool *gradually*. By laying this across a knife blade the exact centre is found and *marked*. By means of a screw-drill a hole about $\frac{3}{32}$ of an inch diameter clear through the centre of this steel 'needle,' as it is called, is bored. By filing from the centre towards the side the needle is brought to the shape of a lozenge, as seen at Fig. 1, A. Holding this needle by means of a piece of copper wire passed through the hole, it is heated to dull redness over a flame and plunged into cold water to restore its temper. A piece of brass rod, $\frac{1}{8}$ of an inch in diameter, and about $\frac{1}{8}$ of an inch long, is now soldered centrally, just over the hole. This is easily done by cleaning the needle with a bit of sandpaper,



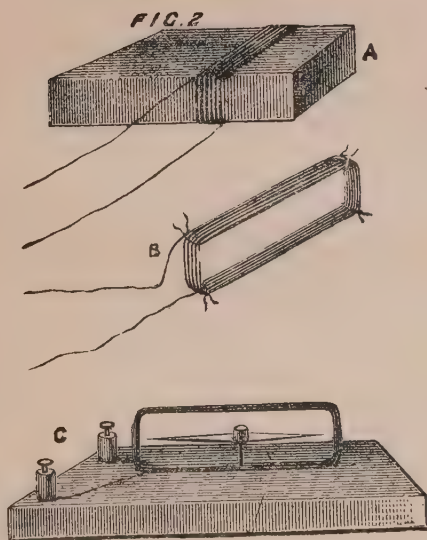
specially round the hole, cleaning also the little piece of brass rod, on its end, then putting a little piece (as big as a grain of mustard-seed) of plumbers' solder just over the hole bored in the needle. Holding the needle with a pair of forceps (a little rosin powder having been previously applied round about the hole) over the flame of a spirit-lamp or gas-burner, will cause the solder to melt and adhere to the steel. The piece of brass is now taken up with another pair of forceps, and laid (flat side downwards) as centrally as possible over the hole. Keeping the needle still over the flame, the solder will also flow round the brass and adhere to it, making a firm junction, when it may be removed from the flame, and placed *at once* on a cold metal or stone surface. It should now present the appearance shown at Fig 1, B. Any solder which may have exuded from between the brass and the steel should be filed away. Using the same bit in the screw-drill that was employed originally to bore the hole, through the steel, a conical hole, reaching nearly but not quite to the opposite surface of the brass piece, is drilled from the hole in the steel. This serves as a pivot on which to poise the needle. A trial may now be made to find whether the needle is fairly centred; but no attempt need be made *yet* to balance it if not true. Having cut off the head of a fine-pointed pin, let us drive it, blunt end downwards, into the centre of a little slab of well-seasoned pine 3 inches by 3 inches by $\frac{1}{2}$ an inch, leaving not less than $\frac{3}{4}$ of an inch protruding. On the point we can poise the needle, and *mark* with a pencil the end which hangs (if either does). Fig 1, C, will show what is meant. The needle must now be *magnetized* by being allowed to remain for some time (twenty minutes or half an hour) across, and in contact with the poles of a horse-shoe magnet, care being taken that having once placed the needle in one position it should not be reversed, as its polarity would be reversed if this were done; and since in our latitude the *north-seeking pole of a freely suspended needle hangs downwards*, if the needle, when tried previous to magnetizing, had one end *heavier* than the other, *that end* must be placed against the north pole of the horse-shoe magnet, by which means it will acquire south-seeking polarity, and consequently neutralize to a certain extent the inclination of the poised needle. After magnetization

it should be again poised, any deviation from the horizontal line noted and corrected by cautiously filing the needle on one of its flat sides, at its heavier extremity, with a fine file, until perfect equilibrium is obtained. Fig. 1, D, illustrates the position in which the needle should be placed with relation to the magnet during magnetization. When the needle has been well balanced it ought to turn very freely on its pivot, making several free swings, but finally taking up a position pointing *north* and *south*. It should also show decided polarity when tested with a magnet; that is to say, one extremity should be strongly *attracted*, and the other just as *strongly* repelled on the approach of the north pole of a horse-shoe or bar magnet. When all these conditions have been satisfied, it will be well to mark with a pencil the letter N on the extremity of the needle, which is *repelled* by the north-seeking (or marked) end of the magnet. This extremity will be the *north-seeking end* of the needle, and is generally (though inaccurately) called its *north pole*.

§ 3. We have now succeeded in making and poising a magnetic needle. In so doing we have learnt two important facts: (a) that *steel* becomes permanently magnetic when placed in proximity to a magnet; (b) that each pole of the new magnet thus formed evinces a polarity of opposite kind to that possessed by the pole of the original magnet which induced its magnetic condition: in other words, the *north* pole of the original magnet induces *south* polarity in that portion of the steel nearest to it, while the *south* pole induces *north* polarity.

Our next step is to surround the needle with a coil of insulated copper wire. To this end a piece of wood $2\frac{1}{2}$ inches wide by $1\frac{1}{2}$ inch thick, and of convenient length to hold in the hand, is prepared as a form, the edges being slightly rounded to admit of the wire being slipped off; this is then wound with about 10 feet of No. 30 silk-covered copper wire, as shown at Fig. 2, A, leaving about 3 inches of wire projecting at each extremity. The four corners of the rectangle thus formed should be bound with silk, so as to prevent uncoiling when the rectangle is drawn off the wooden form. The coil, on removal from the form, should present the appearance shown at B, in which the ends of the silk used to tie the corners are purposely exaggerated in length, the

better to show their position. The centre of the coil being found, the wires forming one of the flat sides are slightly parted by means of a blunt pin (care being taken not to abrade the silken covering, and the coil passed over the pin-point fastened in the centre of the little baseboard above described (§ 2,) and attached thereto with a little dab of hot sealing-wax, or better still, with Prout's elastic cement. The needle is then replaced, and tried, to see whether it oscillates freely without catching at any point in the coil. The two free ends of the wire are now to be denuded of their silk covering, cleaned with a bit of sand or glass paper, and attached to two small binding screws (those known as telephone binding-screws, and sold at most electricians at 1s. 6d. per dozen, will do admirably), inserted one at each corner of the baseboard. The galvanometer or *multiplier* is now complete, and should appear as figured at C. When all is in position, note from which binding-screw starts the wire which goes *over* the needle. Mark this binding-screw by writing 'over' near it. The galvanometer is used to detect the presence of current electricity by causing any such current to pass through the coils of the instrument. For this purpose the two opposite extremities of any circuit, through which it is supposed a current is flowing, are each connected to one of the binding-screws. If a current passes, the needle (which previously must be made to lie parallel with the coil, by turning the baseboard round until the coil points north and south, like the needle) will immediately start out from its position of parallelism with the coil, and take up a position which will approach nearer to right angles with the coil, in proportion as the current is stronger. To test whether the galvanometer just made be fairly delicate, attach a piece of copper wire about $\frac{1}{32}$ of an inch thick and 6 inches long to one of the binding-screws; to the other attach a similar piece of iron wire. Now bring the free ends of the wire (by bending) within $\frac{1}{8}$ of an inch of each other. Turn the baseboard round until the north end of the needle points between the two binding-screws, perfectly parallel to the coil. Put a single drop of vinegar on a little piece of glass, and bring it under the two ends of the wires, which must be lowered until they are both *in* the drop of vinegar, but do not touch each other. By the action of the vinegar on the two



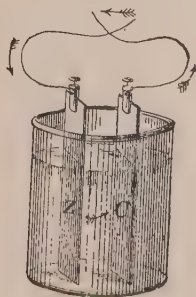
metals, an electrical disturbance is set up, which produces a so-called 'current' which starts from the iron, passes through the vinegar, along the copper wire, through the coils of the galvanometer, and back again into the iron, this action being continuous as long as the vinegar acts on the iron. Simultaneously with this, the needle is seen to deflect from the line of the coil, and if our galvanometer is a success, it should stand out at least 20° from the central line of the coil. Faraday's great discovery, on which all dynamos are based, consisted in proving that a magnet could be caused to excite a current, similar to that produced by the action of acids on metals. We can now repeat his experiment with the aid of our galvanometer. Let A, Fig. 3, be a rod of $\frac{1}{2}$ inch soft iron, about 6 inches long, bent to the shape of the letter U, and wound round its central portion with about 100 feet of No. 24 cotton-covered copper wire, the two ends of which (about a yard each end) having been stripped of their covering, must be attached to the binding-screws of the galvanometer. If a good horse-shoe magnet, B, be placed in contact with the two legs of the coiled U, this latter being kept motionless, while the magnet is alternately approached to and separated from it, it will be found that the needle of the galvanometer is powerfully affected, first in one sense and then in the other, according to whether we *make*, or *break* contact with the U, or *armature*, as it is called. We shall also find that, although the most powerful effects are noticed when actual contact and actual separation take place, yet currents are also produced on approaching or removing the magnet to or from a distance. In other words, *motion in the field of a magnet gives rise to electricity*. A contributor to *Blackwood's Magazine* embodied this fact in the following lines :

' Around the magnet, Faraday
Is sure that Volta's lightnings play ;
But how to draw them from the wire ?
He took a lesson from the heart ;
'Tis when we meet, 'tis when we part,
Breaks forth the electric fire.'

If we study the effects thus obtained, we shall find that they differ in some points very markedly from those obtained by the action of acids on metals (voltaic electricity—galvanism), inasmuch



FIG. 4.

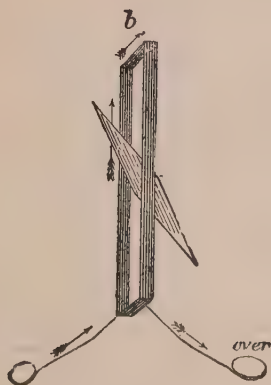
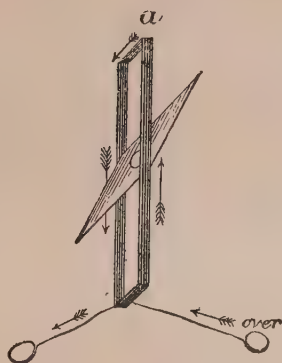


as first, the action is *not* continuous ; secondly, it is contrary in direction when contact is *made* to what it is when it is *broken*

§ 4. The student will do well to compare the effects produced on the galvanometer by the battery current, and by the current obtained from the magnet. Any single cell will do for this purpose ; and in order to have an intelligent perception of what takes place, the student must bear in mind, that *in* the battery itself, the electricity (undulatory movement of the molecules) passes from the zinc to the negative plate (be it copper, silver, platinum, or graphite), while *outside* the battery, the electricity passes from this latter round through the wires, galvanometer, or other circuit open to its passage, back again to the zinc plate. (See Fig. 4, where the direction of the undulation, or 'current,' is shown by the arrows ; the plate marked Z being zinc, the one marked C being carbon, copper, or other conductor ; W W being the wires forming the *poles* or *electrodes*). If the positive pole (the one from which the 'current' is flowing, the wire attached to the C plate) of such a battery be connected to the galvanometer by means of the binding-screw marked 'over,' the other pole being attached to the other binding-screw, the north pole of the needle having previously been adjusted so as to lie between the two binding-screws, it will be found that the north pole of the needle will deflect to the *left* of the line of the coil ; the operator being supposed to be standing at the binding-screw end of the galvanometer. Since the wire of our coil returns *below* the needle, it is evident that a positive current (an outflow of undulation) passing *over* the north pole of a horizontally suspended needle, or a negative current (an influx of undulation) passing *under* such a north pole, causes it to deflect to the *left*.

If we disconnect the battery and reverse the connections—*id est*, join the negative pole (the wire coming from the zinc) to the binding-screw marked 'over,' the other pole being connected to the other screw—the opposite effect results : viz., the north pole now deflects to the *right* of the coil. This will be understood by reference to Fig. 5, in which *a* represents the effect of the positive current flowing *from* the operator *over* the needle, the north pole in both illustrations being nearest to him ; in *b* the positive

FIG. 5.



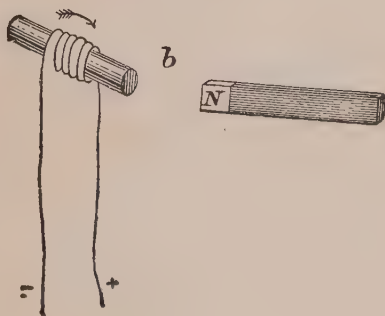
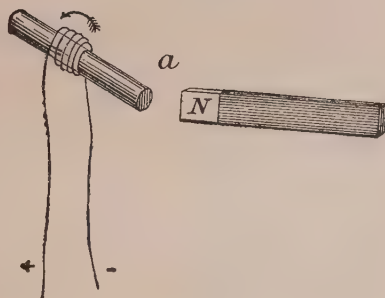
current is supposed to be flowing *from* the operator, *below* the needle, in either case returning to the battery the opposite way.

§ 5. This effect will enable us at once to recognise, by means of our galvanometer, the *direction* in which a current is travelling; for, on connecting the two terminals of any source of electricity to the binding-screws of the galvanometer, whilst the north pole is in a line with the coils, between the two binding-screws, the operator facing the north pole of the needle, it is evident that if the north pole of the needle is deflected to the *left*, the terminal attached to the binding-screw marked 'over' is *positive*; but that if the north pole deflects to the *right*, then the said terminal is *negative*. It must be borne in mind that by the term *positive* in this connection is meant the point *from* which electricity is flowing, negative being the point *towards* which it is flowing, or *at* which it enters.* This power of recognising the direction of a current will be found of great service to us in the construction of the dynamo.

§ 6. Returning now to our experiments with the magnet (see latter portion of § 3), and using in preference a straight soft iron rod, about 6 inches in length, and $\frac{1}{2}$ an inch in diameter, coiled with about 100 feet of No. 24 covered wire as our armature, and a good bar magnet to produce the electrical effects, we shall find, on coupling up the armature wires to the galvanometer, and approaching one end of the armature to or receding it from the north pole of the magnet, that the electrical flow set up is always in one direction in approaching or making contact, and in the opposite direction on receding or breaking contact. Fig. 6 will make this clear. The arrow at *a* shows the direction of the current produced on approaching or making contact with the north pole of a magnet; *b* illustrates the direction of current produced on receding from or breaking contact with the north pole of a magnet. If now we reverse the experiment by presenting the south pole of the magnet to the coiled armature, we

* We have no desire to enter into any theoretical matters in these pages; but comparing electricity to sound, we may say that in blowing a blast in a trumpet, the trumpet may be considered as *positive*, while the ear of the listener may be considered as being negative. The chief difference seems to be that electrical undulations seem to require a complete circuit wherein to display their effects, sound undulations being bound by no such conditions.

FIG. 6.

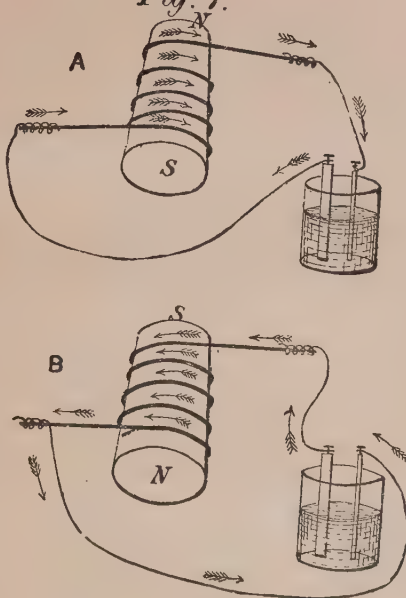


shall find that the direction of flow is also reversed ; that is to say, the *withdrawal* of a south pole produces the same effect as the *approach* of a north pole, and *vice versa*, the *approach* of a south pole is equivalent in its effects to the *recession* of a north pole. It must be noted that the direction in which the wire is coiled round the soft iron rod (or armature), while it has no influence on the direction of the electrical current set up round the iron rod (which is always the *reverse* to the hands of a clock in the face *approaching* the north pole) determines the extremity of the said wire at which the current leaves or enters the coil. In the figure we have supposed the wire to be wound from *left OVER* towards *right* ; had we wound our rod from *left UNDER* towards *right*, the opposite ends of the wire would have been respectively + and -. This must be borne in mind when we proceed to actual work.

§ 7. *Currents can produce Magnetism.*—If we take the coiled soft iron U, of which we made use § 3, and apply it to pieces of soft iron, nails, filings, etc., we shall find that it possesses little or no magnetic power of attraction ; but if we couple the projecting ends of the coiled wires one to each terminal of a single-cell battery, we shall find that the U will become powerfully magnetic, retaining its magnetism as long as electricity flows around the coils, but losing nearly all the instant that the flow is caused to cease, either by breaking connection with the battery, or by any other interruption. The rapidity and completeness with which the iron loses its magnetism depends almost entirely on its *softness* and *purity*. Anything which tends to put a strain on the molecules of the iron, such as hammering, filing, twisting, sudden cooling, vibration, etc., render it liable to retain magnetism, or increase its *coercitive* force ; whereas raising to a high temperature and very gradual cooling, which allows the molecules to range themselves with little or no strain, furnishes a soft iron, eminently incapable of retaining magnetism, or possessing little *coercitive* force.

§ 8. The direction in which the flow of electricity takes place around the iron bar decides which end of the bar acquires *north-seeking*, and which *south-seeking* polarity. Let us suppose, as in Fig. 7, A, that one extremity of the bar be made to face us, and

Fig. 7.



that the current be caused to flow in the direction of the motion of the hands of the clock; in this case, the farther extremity of the bar becomes a *north-seeking* pole, while the nearer extremity becomes *south-seeking*. The direction of the current, and consequently the polarity of the bar, may be reversed by joining up the *opposite* electrodes of the battery (or other source of electricity) to the ends of the wire coiled round the bar, as shown at B; where, as the wire is joined to the electrodes in a manner just the reverse to that shown at A, so also the current enters at the opposite end of the wire, and produces contrary magnetic effects. The same result may also be attained by coiling the wire around the bar in the contrary direction, while leaving the connection with the electrodes unchanged, as represented at C (Fig. 7*a*). Perhaps the simplest means of remembering the relation which exists between the direction of the current and the position of the magnetic poles produced, is one known as 'Ampère's Rule,' in which the experimenter considers himself to be swimming head foremost, *with* the current, along the wire, *always facing* the iron core; *then* the NORTH-SEEKING POLE will always be at his LEFT HAND. (See Fig. 8.)

§ 9. It must be borne in mind, as being of the greatest importance in the construction of successful dynamos, that although *steel*, or hard iron, when subjected to this inducing action of the current, becomes *magnetic*, yet it does not acquire nearly such powerful magnetism as soft iron; and, in fact, the softness of the iron, and its capacity for becoming powerfully magnetic, run side by side. On the other hand, it must not be forgotten, as we learnt at § 7, that the softer the iron the sooner it loses the magnetism imparted to it; while the harder brands of iron (and more especially steel) retain nearly all the magnetism which it is possible to confer upon them.

§ 10. The student who has carefully and intelligently performed the experiments described in the previous sections, will now find himself in a position to understand the principles which underlie the construction of the dynamo, even though he may have little or no previous knowledge of electricity. The first machine constructed after Faraday's discovery was that of H. Pixii, in 1832. In this machine a powerful horseshoe magnet was caused to rotate

FIG. 7a.

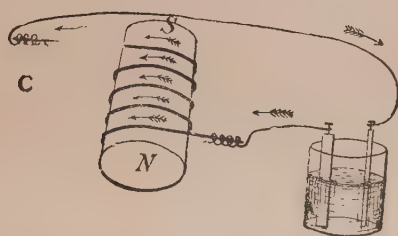
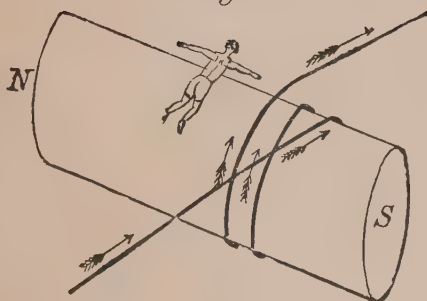


Fig. 8.



rapidly before a soft iron U-piece, wound with insulated copper wire, the two extremities of which were prolonged by two brass springs pressing against a rotating split collar of brass, whose office was to rectify the direction of the currents produced by rotation of the magnet, before the iron core; currents which, as we have seen (§ 4), are in different directions, according to whether a given pole of a magnet is *approaching* to or *receding* from the core. This arrangement for causing alternating currents to flow in one direction, is known as the *commutator*, and it, or some modification of it, is most extensively used in all dynamos in which it is of importance that the current should flow in one direction only. The chief disadvantage in this machine was that of having to rotate a heavy magnet (built up of a number of thin steel plates), since the mere rotation tended to destroy, or at all events, to weaken its magnetism. In 1833 Mr. Saxton had the happy idea of fixing the heavier and causing the lighter portions of the apparatus to rotate: in other words, the magnet (or magnets) was now made a fixture, while the U-shaped soft iron armature, with its surrounding coils of wire, was caused to rotate rapidly before it, on axis or spindle, either by gear-wheels or wheel and band. Mr. E. M. Clarke, in 1834, noticed that the *thickness* of the wire coiled round the armature had a considerable influence on the nature of the current produced by these machines. If the wire employed be very thin, say about the $\frac{1}{100}$ of an inch in diameter, and a large number of convolutions be coiled around the legs of the armature, the electricity produced is of high *tension*, capable of overcoming considerable resistances, and of giving severe shocks. If, on the contrary, a smaller quantity of a much thicker wire, say from the $\frac{1}{14}$ to the $\frac{1}{8}$ of an inch be made use of, the current produced is that known as a *quantity current*, or a 'large' current, possessing but little power of overcoming resistances, not capable of giving shocks, but giving fine large sparks, and able to decompose water, and other chemical bodies. Clarke usually furnished two armatures with his machines, one wound with about 1,500 yards of covered wire $\frac{1}{60}$ of an inch in diameter, which he designated the 'intensity' armature; the other, wound with about 40 yards of wire $\frac{1}{8}$ of an inch thick, to which he gave the name of the 'quantity' armature. One pecu-

liarity of the machines turned out by Clarke was the fact of the rotating U-shaped armature being made to rotate near the flat sides of the magnet instead of *in front* of the poles. This, though it facilitates somewhat the mechanical arrangements, is open to some objections on the score of lesser efficiency, since the most active portion of the magnet is certainly *in front* of the poles. As Clarke's machine embodies nearly all the principles found in later dynamos, we shall give an illustration, together with detailed explanation of the commutator, etc., in our next paragraph.

§ 11. In Clarke's machine the horseshoe magnet, A, Fig. 9, is clamped to a rigid backboard, which is mortised to the baseboard. In front of this magnet, and in close proximity to its poles, is the armature B B', which can be made to rotate on its axis at *c*, which passes right through the backboard, behind which it is supported on bearings. The distant end of the axis is fitted with a pulley, around which plays a band or gut coming from the fly-wheel *f*. On turning the handle of *f*, the small pulley enters into rotation, carrying with it the armature. This armature (which represents the U-piece described at § 3, Fig. 3) is really constructed of three pieces of very soft iron, two short circular bars and a cross-piece, held together by screws, as shown at *b*. Around the two bars is carefully coiled the insulated* copper wire, in such a manner that, if the bars were straightened out, the winding would be always in one continuous direction, either from *left* over to *right*, or *vice versa*, and the two extreme ends of the wire are brought out and joined metalically with the two metal half-cylinders which form the commutator *c*. This commutator is illustrated more fully at Fig. 10 *c*. Against the commutator press the two brass springs *d* and *d'*, to which are connected the wires *e* and *e'*, which form the real *electrodes* or *poles* of the machine. Fig. 10 shows how the wire is wound round the two soft iron cores B and B', which are screwed to the soft iron cross-piece at A and A', thus constituting virtually a coiled U-piece. The two ends of the wire which forms these bobbins come out at opposite sides of the bobbins, and are soldered or screwed to the two half-cylinders (of brass) *c* and *c'*, as shown at *b* and *b'*. In order that the two cheeks of the com-

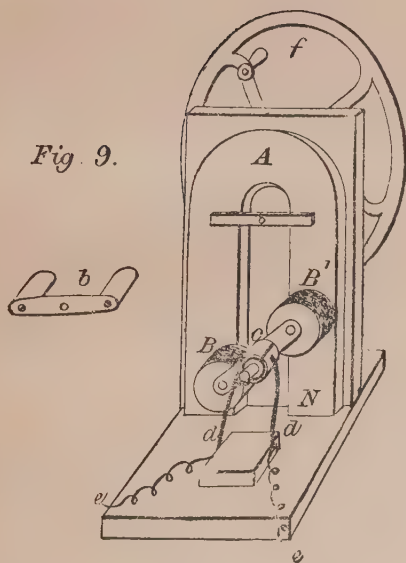
* A body is said to be insulated when surrounded by substances which prevent the passage of electricity.

mutator, c and c' (which are shown separately to the right-hand of Fig. 10), should not allow the electricity to escape from one to the other, the spindle which carries the bobbins $B B'$ and the cross-piece $A A'$, is encased in a thick ring of ivory, baked boxwood, or other insulator, which in the illustration is shaded darkly.

FUNCTION OF THE COMMUTATOR.

§ 12. If we follow one of the bobbins of the armature during its revolution before the poles of the magnet, we shall find that it changes its magnetic condition, and consequently its electrical state, *twice* during each revolution. Let us take, for instance, the bobbin B' in either figure in its rotation from the north pole of the magnet towards the south pole : as we learnt at § 6, *leaving* a north pole or *approaching* a south pole produces the same effect; and this effect will be that a current will flow round the bobbin from the right over towards the left. Hence, if the wire (which is coiled round the bobbin in the same direction) have its corresponding extremity joined to any circuit, this extremity will be found to be negative. In practice this extremity is actually connected with the cheek c' of the commutator. This cheek c' during the whole of the semi-revolution of the bobbin B' from north to south, is being pressed against by the spring d' , which, with its wire e' , is consequently kept continuously in a negative state until the bobbin B' has arrived quite opposite the south pole of the magnet. At this instant the spring d' touches neither of the brass half-cylinders, but presses against the ivory, boxwood, or other insulator, which separates the two half-cylinders of the commutator c and c' . Hence, no current flows; but directly B' leaves the middle of the south pole and begins to complete the under-half of the revolution, its cheek comes into contact with the spring on the opposite side, d . But now we find that the bobbin B' is leaving a south pole to approach a north pole; therefore, according to § 6, the current is flowing in the opposite direction round the bobbin. Therefore the spring d collects from the cheek c' *positive* electricity. What has been said of bobbin B' is, of course, equally true of bobbin B at similar points of its revolution; hence we see that, although each bobbin becomes alternately north and south as it approaches the south or north pole of the permanent magnet,

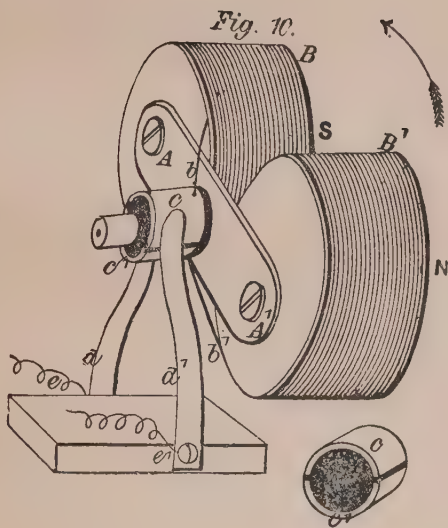
Fig. 9.



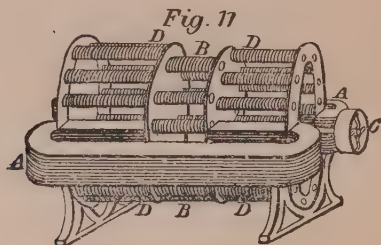
and sends therefore a current alternately in contrary directions, yet, since (owing to the insulated half-cylinders) we are able to cause *one* spring to pick up the current from the bobbins whilst the free extremity of their encircling wire is sending a positive current only (the *other* spring picking up the current only whilst the free extremity of the coiled wire is negative), it follows that the springs *d* and *d'* are maintained in oppositely electrified conditions. It must be borne in mind that the wire is coiled continuously round both bobbins; hence, that as the bobbins are always exposed at the same time to opposite magnetic influences, so the conditions of the two extremities of the coiled wires are electrically opposite—viz., while one is *positive* the other is *negative*, and *vice versa*; but that as the bobbin, whichever it be, which travels from north over to south has the free extremity of its wire always *negative* and in connection with the spring *d'*, while the bobbin (each in turn) which passes under from south to north has its extremity always *positive* and in connection with the spring *d*, it follows that, providing always the motion be that indicated by the arrow in Fig. 10, the spring *d'* will always be kept in a *negative* condition, while the spring *d* will simultaneously be *positive*.

Since the comprehension of the function of the commutator is of the highest importance in the manufacture of the dynamo, we recommend the amateur to digest carefully the contents of this last section.

§ 13. The next great step in the development of the dynamo was the application of the current generated by the armature to the heightening of the magnetism of the magnets which set up that current in the armature. We have seen (§ 7) that a current sent round a mass of soft iron converts that iron into a magnet; and we find that the intensity of magnetisation is, up to the point of saturation, proportionate to the quantity of electricity flowing round the iron. We also know that magnets produced by such means (*id est*, the passage of currents *around* soft iron cores) are much more powerful than permanent steel magnets of equal size and weight. Hence, apart from the question of less expense and greater constancy (for steel magnets gradually lose their power by the continuous motion of the armatures before their poles), there is actually a great gain in efficiency in employing *electro-magnets*



instead of *permanent magnets* wherewith to induce the current. In Hjorth's machine (which was perfected so far back as October, 1854) two compound cast-iron magnets, A A (Fig. 11), which may or may not be surrounded by a coil of wire, are bolted to the frame of the machine. These magnets are shaped like the letter C; and in the gap between the poles rotates a wheel, B B, on the circumference of which are fastened several armatures consisting of soft iron cores wound with insulated copper wire, the ends of which are brought out to a peculiarly constructed commutator, which rectifies the dissimilar currents produced. The wheel (and consequently the armatures) is caused to rotate by means of the rigger C and driving-axle. Around these movable armatures, and also bolted to the frame, are several soft iron cores wound with



insulated copper wire, D D D D. The currents produced in the first instance by the passage of the armatures before the poles of the magnets, A, after being rendered uni-direction by means of a commutator, are led on through wires to the coils which surround the soft iron cores, D D D D. These become, therefore, powerful electro-magnets, and induce in their turn more powerful currents in the armatures. The larger currents thus produced, again reacting in their passage on the electro-magnets, superinduce a higher state of magnetism in them, and this again exalts the electricity generated in the armatures, and so on until the limit of saturation is reached. The current, after traversing the coils, is led to terminals to which connection can be made for exterior work.

It is remarkable that, although this discovery was so important, and the description and designs were so clear in the specification,

so little attention should have been attracted to it. Soren Hjorth was, indeed, much before his time, many of the machines now doing excellent work being simply trifling modifications of his 'magneto-electric battery.'

THE SIEMENS ARMATURE.

§ 14. The intensity of electric and magnetic effects does not increase in the simple proportion of the nearness of the bodies acted on, but in a much greater ratio, which, in the case of electrified bodies and permanent magnets, is *directly as the square of the nearness*, or (what amounts to the same thing) is *inversely as the square of the distance*. For instance, we find that a magnet which exerts a 'pull' of 1 lb. on a given piece of iron at 6 inches, if placed at 3 inches, or *twice* the nearness, pulls with a force of $2 \times 2 = 4$ lb.; and if placed *four* times as near, namely, $1\frac{1}{2}$ inches, pulls with a force of $4 \times 4 = 16$ lb.

It would appear that in the case of electro-magnets the ratio between the distance and the effect increases even more rapidly, being, according to the best authorities, equal to *inversely the cube of the distance* nearly. Hence, it struck Dr. Werner Siemens, of Berlin, that if the armature could be constructed of such a form as to allow of its remaining always very close to the poles of the magnet during its rotation, greatly exalted electrical effects would result; and in 1856 he patented in this country the special form of armature represented at Fig. 12 *a*, so well known as the 'Siemens' or 'H-girder' armature. On reference to the armatures depicted at Figs. 9 and 10, it will be seen that during a considerable portion of their rotation they are at some distance from the legs of the magnets, and even when near them are not at the points of greatest action.

On the contrary, the Siemens armature is placed as nearly as possible at the most active portion of the magnet's poles—viz., their extremities, and at every portion of its rotation some portion of the armature is exposed to the action of the said poles. The Siemens armature, as shown at Fig. 12 *a*, consists of a cylinder of soft iron, between three and four times as long as its diameter, around the sides and ends of which is cut a deep groove or channel, rather more than one-third the diameter of

the cylinder. This is shown in section at *b*. The soft iron cylinder, *c*, has brass heads and axes fitted to it, as shown at *f* and *g*—the latter carrying a pulley or *rigger*, by which the armature can be rotated; while the former is encircled by the commutator, *e e*, to which are attached the two ends of the insulated wire, which is wound in the channel. When in action this armature is placed between the poles of a compound horse-shoe magnet, and supported on trunnions or bearings at both ends; two springs pressing against the commutator carry off the electricity generated by the rotation of the armature, the motion being imparted by means of a band passing over the pulley at the farther end of the armature. A general idea of this arrangement may be gathered by inspecting Fig. 12 H.

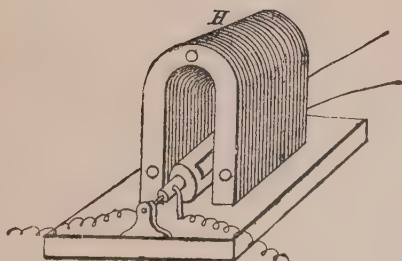
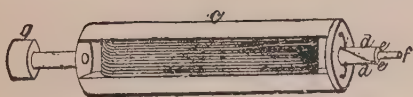
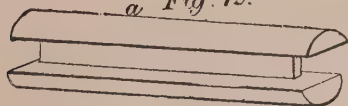
CURRENTS GIVEN BY THESE MACHINES NOT CONTINUOUS.

§ 15. Since the direction of the current changes at every semi-revolution of the armature in such machines as those of Clarke, Pixii, and Siemens, and at every passage of the compound armature before the poles of the inducing magnets in Soren Hjorth's machine, we are constrained to use a commutator whenever we desire to produce a current in one direction only. But the commutator, by the very fact of its being necessarily constructed of two or more portions of a metallic cylinder, separated by intervals of insulating material, interrupts the passage of the electricity every time that the springs press against the insulating spaces. Hence the electricity furnished by these machines partakes more of the nature of rapidly succeeding waves, than of a steady continuous current, like that furnished by the battery. Still, when the armature is rotated at a high speed (and the Siemens requires to be driven at about 3,000 revolutions per minute, to give the best effects), these waves succeed each other with such rapidity as to simulate a steady current, no break in continuity being perceptible to ordinary tests.

RAPID MAGNETISATION AND DEMAGNETISATION PRODUCES HEAT.

§ 16. It is found that the sudden change from north magnetism to south magnetism, which takes place in each half of the above

a Fig. 12.



described armatures, as they pass over from before a south pole to before a north pole of the inducing magnets, is accompanied by a very considerable rise in temperature; and that this rise increases with the rapidity of change of magnetism, which in its turn depends on the rapidity of rotation. So marked is this rise of temperature, that a dynamo fitted with a Siemens armature of the pattern figured at § 14, and started at an initial temperature at 10° C., rises in about twenty minutes to nearly 50° C., when driven at 3,000 revolutions per minute. This rise in temperature is detrimental to the efficiency of the machine:—1st. Because the wires of the armature, becoming heated, conduct less freely; hence loss of current. 2nd. Because the armature itself is not capable of such intense magnetisation when hot as when cold (a red-hot mass of iron is hardly affected by the magnet); hence another loss of current. 3rd. Because the insulating covering of the wire is impaired, even if not actually ruined, if the temperature exceeds a very moderate limit.

For these reasons it is important to keep the temperature of the armature as low as possible. The first successful step in this direction was taken by Dr. Pacinotti, of Florence, in 1860, who constructed an armature of soft iron, in the shape of a ring, around which were coiled, in successive sections, helices of insulated copper wire, the ends of which were joined up to a divided ring commutator. The ring armature of soft iron, with its covering of wire, was supported on a central axle, and rotated before the poles of a magnet, either permanent or electro. At no part of the revolution is such a ring taken as a whole farther from, or nearer to, the poles of the magnet; and although its magnetism is constantly changing, yet the change is not abrupt, but gradual and continuous; as will be explained in the following paragraph.

PACINOTTI'S RING ARMATURE

§ 17. The description and illustration of this machine is to be found in the *Nuovo Cimento* for the year 1864, under the heading of 'Una Descrizione d'una Piccola Macchina Elettro-Magnetica.' The machine itself, as described, can be used either as a motor, or as a generator of electricity; and its adaptability to either

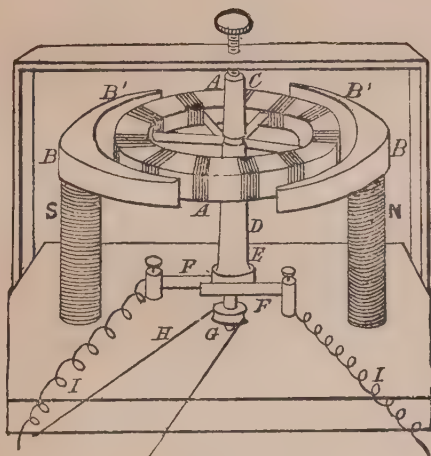


Fig. 13.

PACINOTTI'S RING ARMATURE.—A A, The iron ring, enveloped with coils of wire. B B B' B', Soft iron prolongations, or 'horns' of the electro magnets S N. C D, Central axis, on which the ring A turns. E, The commutator, to which the ends of the coils of wire are joined. F F, The brushes. G, The pulley, driven by the band H.

purpose was specially dwelt upon by Dr. A. Pacinotti, in his communication; but it is only under the aspect of a generator that we shall stop to consider it here.

Two electro-magnets, S, N, Fig. 13 (which may, or may not, be united together below), are fastened to a base-board, and so arranged that the upper extremity of one is a north pole, while the other is a south pole. These poles are furnished with semi-circular prolongations B B, B' B', between which is poised, on the axis C D, a soft iron ring A A. This ring is attached to the axis by means of radial arms. Coils of insulated wire are wrapped round the ring at short intervals about its periphery, the end of each coil being brought down the axis at D and attached to one of the small copper strips at E (of which there are as many as there are coils around the ring), the wire beginning the next coil being also metallically connected to this same strip. The wire terminating the next coil is fastened to the next strip, from whence starts a fresh coil, and so on, until all the strips, which form the compound commutator E are connected to the coils in such a manner that the end of one coil, by its attachment to its strip, forms the commencement of the next. Consequently, the wire forming the coils, although capable of communicating electrically with the springs F F at opposite points of the diameter of the commutator, is really continuous. The ring A A is caused to rotate by means of the rigger G and the driving belt H.

It will be evident on reflection that the half of ring opposite the pole marked N will acquire by induction *south magnetism*, while the half facing the pole S will for a similar reason become *north*. Hence the ring, whether in motion or at rest, will, provided the electro-magnets be active, become a circular magnet, with the south pole facing the north pole of the electro-magnet, and its north pole facing the south pole of the electro. When the ring is rotated, though, if viewed as a whole, this magnetic condition remains unaltered, yet, of course, any given portion of the ring will gradually change as it passes over from one 'horn' or prolongation of the magnets to the other. Still, the change which takes place is not abrupt, but gradual, and partakes more of the nature of a *wave* than of *shock*. So also, since the springs of the commutator press on several strips at the same time, at no

time is contact ever entirely broken between the commutator and the springs ; therefore the current which is produced as a continuous wave, *always in one direction*, is collected in a similar continuous manner by the springs F F, and may be employed where required by coupling up the wires I I.

This machine, discovered more than twenty years ago, embodies all the essential characteristics of the best modern machines, and the much-vaunted machines of Gramme, Brush, Siemens-Alteneck, Maxim, Edison, etc., are, at best, but trifling modifications of the Pacinotti ring machine—modifications which have not always been improvements. Having now brought our brief sketch of the essentials of a dynamo to a close, we shall proceed in our next section to constructive details.

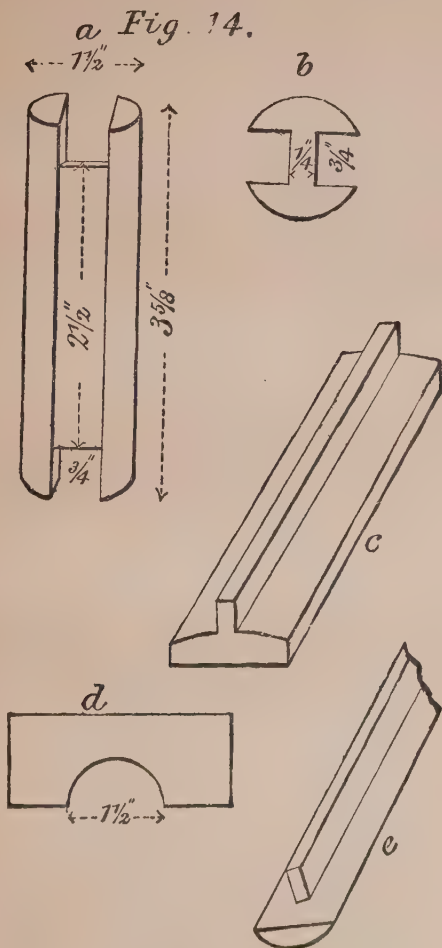
THE PATTERNS.

§ 18. In the dynamo we are about to construct, three separate pieces for patterns are absolutely necessary—viz., one for the armature, one for the legs of the field magnets, and one for the standard which supports the flywheel. There is no necessity for the amateur to put himself to the trouble of cutting out a pattern for the flywheel, since such wheels with handles already fixed can be had for two or three shillings. In constructing the wooden patterns, from which the iron castings are afterwards to be procured, the amateur should remember to choose dry, well seasoned wood, free from knots. Red pine, for such small work as is required, will be found as good as any. Any joints that are absolutely necessary (and joints should be avoided as much as possible) should be attached together with dowels and Prout's elastic glue. It must be borne in mind that the pattern-moulder places the patterns in *green* (moist) sand, and that this moisture causes ordinary glued joints to come undone or expand. Any roughnesses left on the pattern also swell up, catch the sand, and thus destroy the sharpness and beauty of the mould, and therefore of the resulting casting. It is therefore advisable, after having got the wooden pattern to the highest possible degree of smoothness and trueness by means of emery-paper, etc., to give it a coating of melted paraffin wax, and polish the surfaces carefully with a roll of flannel. This renders the surfaces not only

extremely smooth but impervious to moisture, so that the pattern does not warp or swell when placed in the sand. In order that the pattern should come clean out of the sand and not break away any portion of the mould, care must be taken that the edges be slightly rounded, so as to give what is technically called *clearance*. The possessor of a *lathe* can turn up many portions of the fittings with much greater accuracy and rapidity than one provided with only ordinary tools; but in the ensuing directions the amateur is supposed to possess tools of the simplest kind only.

§ 19. The pattern for the *armature* first demands our attention. When completed, it presents the appearance shown at Fig. 14, *a* being the elevation and *b* the section, on a scale of about half the real size, and consists of a wooden cylinder $1\frac{1}{2}$ inches in diameter by $3\frac{5}{8}$ inches in length, with a deep channel round the ends and sides. To construct this pattern, procure a piece of pine 8 inches long by $1\frac{1}{2}$ inches wide and $\frac{3}{4}$ of an inch thick. Lay this on a table on its widest side, and draw a line along its whole length, that shall divide it into two halves of $\frac{3}{4}$ of an inch each. Now, draw a line on each side of this central line, rather better than $\frac{1}{8}$ of an inch from it. Holding a metal rule against one of these side lines, with a sharp penknife, cut into the wood along the line to a depth of about $\frac{3}{8}$ of an inch—rather less than more. Now, perform the same operation on the other side line to the same depth. With a sharp $\frac{1}{2}$ inch chisel, shave away the wood on the outside of the cut lines to the depth of $\frac{3}{8}$ of an inch on the outsides, but *rising up very slightly toward the centre*, as shown at Fig. 14 *c*. This precaution will ensure the pattern lifting out clear from the mould.

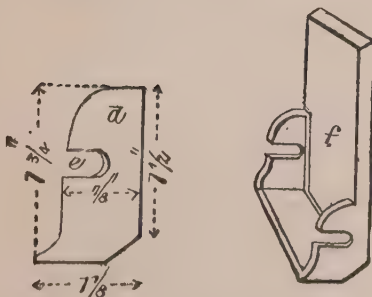
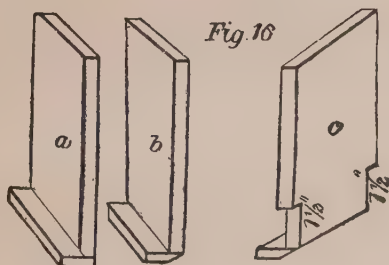
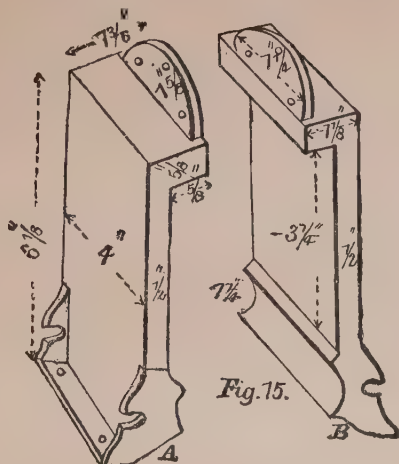
Now, take a piece of stout cardboard, and with a pair of compasses strike out a circle $1\frac{1}{2}$ inches in diameter. Cut the circle out of the cardboard so as to leave a clean circular aperture of the diameter specified. This is to serve as the *templet*, or gauge, of the size and general truth of our armature. Strike out, also, in a similar manner a circle in a piece of stoutish zinc, or tinned iron, also $1\frac{1}{2}$ inches in diameter, and cut this in two halves (one of which is shown at *d*). These will serve to shave away the last irregularities from the wood, when it has been roughly trimmed



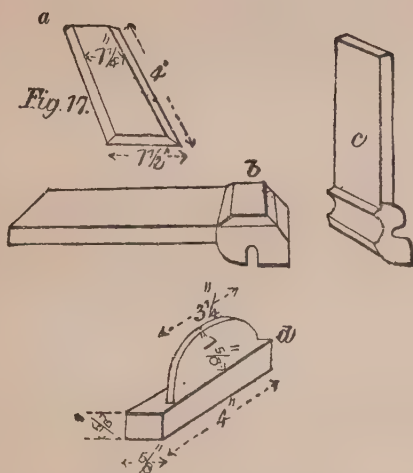
up to the shape shown at *e*, by means of a small plane, or pen-knife. The piece may now be cut into two halves across its length, dowelled and fastened together with Prout's elastic glue, and cut down to the exact length required — namely, $3\frac{5}{8}$ inches. All roughnesses should now be carefully sand-papered, and care should be taken that the finished pattern should pass exactly through the cardboard pattern, being appreciably neither thicker nor thinner at any part. When this has been effected satisfactorily, a small quantity of paraffin wax (a piece of paraffin candle will do) should be melted in an iron spoon, and well rubbed into the pattern at all points with a roll of flannel until it is thoroughly impregnated with the wax; rubbing the pattern until it acquires a polish completes the operation, and renders it ready for the foundry. The thin central portion, which joins the semi-circular portions, should be about $2\frac{1}{2}$ inches in length, having rather more than $\frac{1}{2}$ an inch cut away at each end, so that the channel is continuous round the armature, being $\frac{3}{4}$ of an inch wide and about $\frac{1}{2}$ an inch deep all round.

§ 20. The pattern for the *legs* of the electro-magnet (*field magnets, exciting magnets*) will next require our care. Since the two legs are exact counterparts, the one of the other, so we need only make one pattern, from which, however, *two* castings must be obtained. Fig. 15 illustrates the form and dimensions of this pattern on a scale of about one-quarter the real size. The dimensions are marked in inches. A represents the outside view, *i.e.*, as seen from the side which is farthest from the armature; B gives the view from the inside (close to which the armature rotates).

To make this pattern, procure a piece of pine 6 inches in length, 4 inches in width, and $\frac{1}{2}$ an inch thick, planed smooth, and free from knots and roughness. Glue and dowel along the bottom edge a strip $1\frac{1}{8}$ inch wide, 4 inches long, and $\frac{1}{4}$ of an inch thick, as shown at Fig. 16, *a*. Now, with a sharp plane, remove half the inner edge, as shown at Fig. 16, *b*, so that it makes an angle with the edge of the 6-inch piece. With a fine saw cut a recess on each side of the jointed piece $1\frac{1}{2}$ inches long by 4 inches deep, as shown at *c*, and glue and dowel in each recess the two flanges, made of $\frac{1}{4}$ -inch stuff, of the shape and dimensions

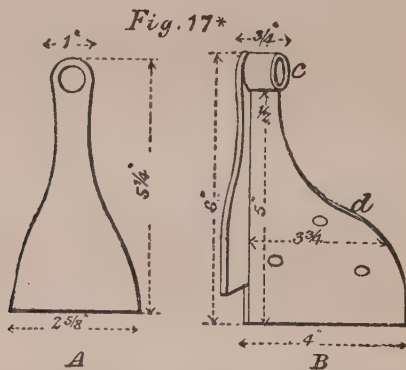


given at *d*. To insure the slot *e* being exactly at the same point in each flange, the two flanges, after being roughly shaped with a fretsaw, or otherwise, should be clamped together, and the finishing touches given with a rat-tail file, for the slot *e*, and with sandpaper along the rounded edges. Care must be taken that these flanges should be a trifle thinner near the edge marked $1\frac{3}{4}$ than on the opposite edge, to insure the pattern coming out clean from the mould. For this reason the slot *e* must not be narrower at the outside than at the inside, but rather the contrary. The slot *e* must be $\frac{1}{4}$ of an inch wide, and must reach in depth to the 6-inch piece, to which the flanges are attached. At this point our pattern will present somewhat the appearance shown at *f*. A piece of wood 4 inches long by $1\frac{1}{2}$ inches wide, and $\frac{1}{4}$ of an inch thick, perfectly smooth, square, and free from knots, must now be chosen, and the two sides planed away, on the upper side to such an extent as to make an angle of 60° with the base. (See Fig. 17, *a*.) With some good thin, hot glue (not Prout's), this piece is to be glued along the bottom edge of the 6-inch piece, on the side opposite the flanges, and in such a manner that the slope of the base is continued by the slope of the piece, as shown at Fig. 17, *b*. When the glue is quite dry, by means of an inch gouge, cautiously hollow out along the entire length of this piece, in a semicircular form, nearly to the depth of the original 6-inch piece, so as to fit accurately the pattern of the armature which has already been made. (§ 19.) When this is as true and smooth as it can be made with the gouge, fold a piece of fine glasspaper over the pattern of the armature, rough side outwards, lay the armature in the channel, and work it backward and forward until perfect smoothness and a perfect fit are insured. The pattern should now present the appearance given at Fig. 17 *c*. When this end has been attained, four small dowels should be inserted into the thicker portions of this semicircular piece, to hold it firmly down to the 6-inch piece. We now need only make the top flange, by which the bracket or standard that bears the wheel is clamped to the legs of the dynamo. This is made most easily in two pieces, one being squared up to 4 inches long, $\frac{5}{8}$ of an inch thick by $\frac{5}{8}$ of an inch wide. The other piece is to be $\frac{3}{8}$ of an inch thick, and must be cut into a perfect semicircle, with a radius of



PORTIONS OF THE PATTERN OF THE FIELD-MAGNET.—*a*, The unfinished cheek ; *b*, The limb with the cheek in its place ; *c*, The cheek hollowed out ; *d*, The top flange, to which the bracket is fastened.

$1\frac{1}{2}$ inches. By means of Prout's glue and a couple of dowels, this is neatly attached to one side of the other square piece, as illustrated at Fig. 17 *d*, and then the whole is carefully and squarely glued and dowelled, in like manner, to the top of the 6-inch piece, so that it now presents the appearance shown at A and B, Fig. 15. The holes shown in the bottom and top flanges may be bored, and core prints inserted, *if the founder will take the trouble to put them in his mould*; but, as a rule, founders do not care to cast small castings with holes in them, as they seldom come true, so that it will be, perhaps, as well to have them bored afterwards, which can be done at a cost not exceeding 2d. a hole. This pattern must now be carefully smoothed, the sharp edges



rounded, to insure parting from the mould, and finally paraffined and polished, as recommended for the armature (§ 19), when it will be ready for the moulder.

§ 21. The next pattern to be made is that of the *standard*, which supports the driving-wheel. This should be made out of $\frac{1}{4}$ -inch stuff, a piece of which $5\frac{1}{4}$ inches long by $2\frac{5}{8}$ inches wide must be cut to the shape shown at A, Fig. 17* (one-quarter the real size). In order not to split the top while boring the hole, it is as well to core the hole (which should be $\frac{1}{2}$ an inch in diameter) before shaping the piece. For the same reason, the piece marked C, which should be $\frac{1}{2}$ an inch thick and 1 inch in diameter when finished, should be glued to the centre of the top end of the piece

A, and the whole bored (by means of a brace and sharp $\frac{1}{2}$ -inch centre-bit) before trimming up to shape. From the same $\frac{1}{4}$ -inch stuff, another piece, figured at B, is cut out, being $\frac{1}{2}$ an inch wide at the top, sloping gradually, and becoming wider to about half its length (*d*) when it should sharply curve to a width of 4 inches. The length of this piece should be 5 inches, and it is to be glued and dowelled to the centre of the piece A, close against the boss C, as shown at B. A small piece *e* must now be glued and dowelled to the edge of the curved flange, so as to make it flush with the front A. When this has been smoothed and polished with paraffin, the patterns are ready for the foundry. The three holes shown at *d* may be bored in the castings.

THE CASTINGS.

§ 22. The patterns may now be sent to the foundry, with the following instructions: First, the armature should be carefully annealed, so as to constitute a *malleable iron casting*; second, two legs should be cast from the pattern shown at Fig. 15, and these also must be carefully annealed, and be made as soft as possible; third, the standard (Fig. 17*, B) will be better if left pretty hard, as in this way it will retain sufficient magnetism to start the machine without adventitious aid. Particular stress must be laid on the importance of the iron in the armature and legs being *very soft*, since much of the efficiency of the dynamo will depend on this point. (See § 9.) When the castings return from the foundry, their degree of hardness may be tested by trying with a rather coarse file. If the file bites easily, the iron is fairly soft; if it slips over without filing, it is altogether too hard. (This does not apply to the standard, which may be left quite hard without any detriment to the machine.) The armature must now be cleaned and trued up. If the student be the happy possessor of a lathe, this will not prove a difficult job; if otherwise, he may, by careful filing, remove any irregularities, and square up the ends. These must be made quite true; otherwise it will be impossible to centre the armature so as to rotate it between the poles of the magnet. The thin central portion shown at *a*, Fig. 14, and there marked $2\frac{1}{2}$, must have its edges rounded, so as not to cut the wire, which will have to be wound round it. No trouble should

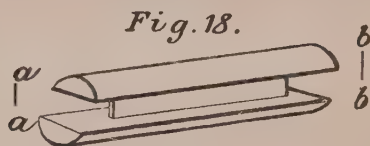
be spared to get the armature as truly cylindrical as possible; as care expended at this portion of the process will render the remainder of the work very much easier, and more satisfactory. The armature having been thus rendered true, the legs will demand our attention. Having gone over the surface with a bastard file to remove any irregularities, the curved channels, shown at A and B, Fig. 15, must be carefully cleaned out. Perhaps the quickest way to do this, and to clean the armature at the same time, is to lay the two pieces, channels uppermost, on a table, putting a little fine sand and water in the channels, and then to work the armature up and down the channels, first in one and then in the other, alternating also the sides of the armature, until the channels, as well as the external surfaces of the armature, are rendered quite smooth and bright. The sharp corners of the legs of the magnets around which the wire has to be coiled must also be rounded, and the top semicircular flanges, between which the standard has to be clamped, must be filed quite flat on their inner surfaces, and made perfectly parallel with the portions marked $3\frac{1}{4}$ B, Fig. 15. The standard must also be cleaned in like manner, particular care being taken that the two sides of the piece marked B, Fig. 17*, be perfectly parallel. The edges of the front piece *e* must be made perfectly square and true, so as to fit exactly on to the top of the two legs of the magnets, Fig. 15.

§ 23. Before winding the armature and field-magnets with the wire in which the electricity is at once generated and conducted, it is necessary to fit together accurately the different portions, and *mark them*, so as to be able to put them together again in precisely the same position after winding; since no filing or fitting can be attempted on the castings after the wire has been wound without almost certain destruction of the insulation, and certain ruin to the neat appearance of the evenly-laid wire.

The part that calls for the greatest care and attention is the armature, which, as it must rotate in very close proximity to the poles of the field-magnets at a rate varying from 1,000 to 3,000 revolutions per minute, requires to be centred most accurately on its bearings or trunnions. This to the possessor of a lathe

presents but little difficulty; for the benefit of those who depend on ordinary tools only, the following method, by which the armature can be mounted on its bearings in a fairly accurate manner, is described. With a pair of calipers, the diameters of the two opposite extremities of the armature are taken, as shown at Fig. 18, *a* and *b*. (If the armature casting were finished up quite exactly, these two measurements would be exactly alike, viz., a trifle under $1\frac{1}{2}$ inches each. But unless turned on the lathe, it is very rare to get such precision.) Two circles, of exactly the same diameters as the two extremities of the armature, are now to be struck out of a piece of hard sheet brass, $\frac{1}{8}$ of an inch thick, care being taken to mark the centre and the circumference in an exact and bold manner with the compasses. These circles will have to be cut out of the brass with a saw or file, so as to get two discs, fitting each one to its respective armature extremity; but before cutting out the circles thus marked, three holes should be drilled in each, viz., one in the exact centre $\frac{3}{16}$ of an inch in diameter, which is to take the driving shaft or trunnion, and one on each side of this centre, $\frac{1}{8}$ of an inch in diameter, to admit the screws which serve to attach these *heads* or discs to the iron portion of the armature. Besides these three holes, which are common to both 'heads,' another pair, also $\frac{1}{8}$ of an inch in diameter, must be drilled in one of the heads, to allow the ends of the wire which is to be coiled around the armature to emerge from them, and pass through to the commutator. All these holes are shown *full size*, and in their correct position at Fig. 19, where *a* is the central aperture, to take the shaft; *b b* the two holes to admit the screws, whereby the heads are attached to the armature; and *c c* holes drilled in one head only, to admit of the passage of wires to the commutator. These holes being bored, and the discs accurately cut out, two pieces of hard-drawn iron wire (not galvanized) $\frac{1}{4}$ of an inch diameter and 2 inches long, are carefully straightened, and by means of a screw-plate, a thread is put on one end of each. With the corresponding tap, a female screw is cut in the central hole of each brass disc. The two iron rods are then screwed in, particular care being taken that they enter perpendicularly and centrally. They must be screwed in until they just protrude through to the other side; then the long

end being allowed to slip between the jaws of a vice, while the disc rests flat upon the surface of the jaws, a few steady blows with a flat-pened hammer will spread the head of the screw end of the iron rod, so as to rivet it firmly to the disc, and thus prevent it working out. To render assurance doubly sure, a drop or two of soft solder may be run round the flat side of the end of the rod and disc. Now we come to a part of the work that very few amateurs can do at home—viz., drilling the holes in the faces of the armature. Any blacksmith will, however, do this for a few pence. Four holes are required, two at each end of the armature (one end is shown real size at *d d*), and these holes must be tapped with a female screw, so as to take the screws which serve to unite the whole together. It will be well to let the blacksmith drill and tap these holes to any sized screw that he has nearest approaching $\frac{1}{8}$ of an inch in diameter. Now will be also



the time to get the blacksmith to drill the three holes, right through the top end of the legs and standard, which serve to allow these portions to be clamped together by means of bolts and nuts. These holes should be about $\frac{1}{4}$ of an inch in diameter. Further details as to position and size will be given a little farther on. If our work has been properly performed, the heads may now be screwed down to the armature with cheese-headed screws, which should project about $\frac{3}{16}$ of an inch above the level of the discs. Fig. 20 gives a representation of the finished armature about half the real size.

§ 24. Our next proceeding is to clamp together the standard, or bracket, which serves to support the wheel to the two legs of the field-magnets. At the concluding portion of § 23, we adverted to the advisability of getting the holes bored right through the top end of the legs and standard, at the same time that the holes

Fig. 19.

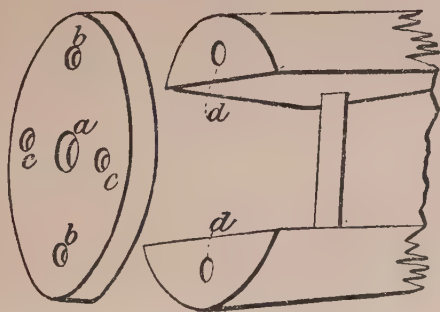
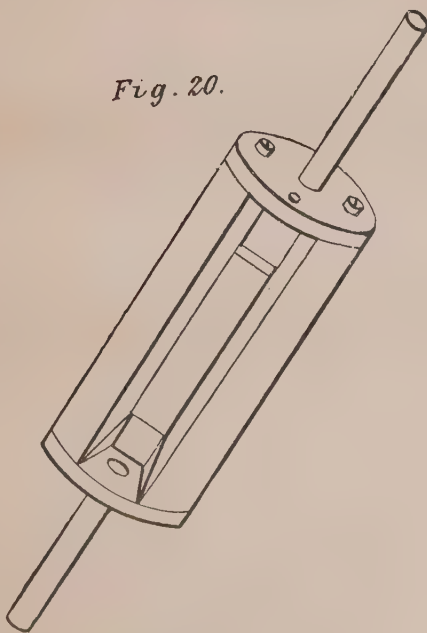
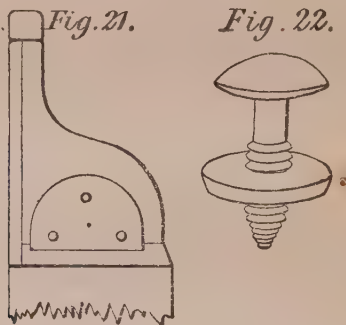


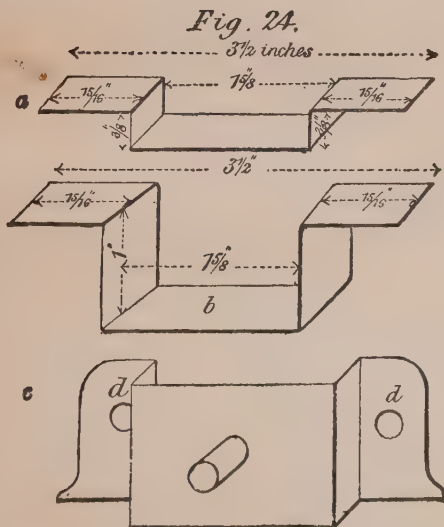
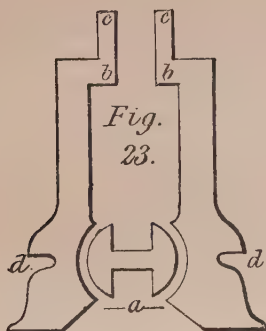
Fig. 20.



were being drilled in the armature. The position of these holes is indicated at Fig. 21 ; they should be about $\frac{1}{4}$ of an inch in diameter, and the two lower ones should be at least $\frac{5}{8}$ of an inch from the bend of the flange, so as to allow the nuts to be easily turned and tightened up. These two bottom holes should be about 2 inches apart, while the upper one should stand equidistant from the others, but at about $\frac{1}{2}$ an inch from the top of the flange. The amateur will find at any of the good furnishing ironmongers, very neat skate-screws with nuts to fit, of the form illustrated at Fig. 22. These screws have usually rounded heads, without the slot for the screw-driver to enter ; but these can be easily cut with a metal-saw. Of course, any small bolts and nuts



having a section of about $\frac{1}{4}$ of an inch will do, but the ones mentioned are very neat in appearance. The holes being drilled and the bolts and nuts chosen, the bracket and limbs of the field-magnet may be temporarily clamped together, in order to see what opening is left between the legs for the armature to turn in, at *a*, Fig. 23. In all probability some filing of the faces of the flanges and of the bracket will be necessary to insure a proper fit. A well-fitted armature, if placed in the centre of the channels at *a*, should leave a space of a trifle more than $\frac{1}{20}$ of an inch to turn in ; that is to say, there should be rather more than $\frac{1}{40}$ of an inch clear space all round between the armature and the field-magnets. Perhaps the quickest way to insure this distance being obtained is to roll tightly a single fold of stout brown paper round the



armature and seal down the edge to prevent it slipping; then, having inserted the armature in the channels, to file away at the inner faces of the flanges, either towards the lower portions at *b b*, if the channels are too wide apart, or at the upper extremities at *c c*, if too close, until the whole fits accurately together. It is needless to remark that when the armature thus wrapped in paper is placed between the field-magnets, to obtain a correct fit, *the solid portions of the armature should lie against the legs, and not the portion of the armature which is hollowed out for the reception of the wire.* (See Fig. 23.)

§ 25. The magnets and brackets being thus properly clamped together, the hole in the top of the bracket (which ought to have been left in the casting, but if not may be bored now) should be cleaned out to $\frac{1}{2}$ an inch in diameter. When this is done, two pieces of hard rolled brass sheet $\frac{1}{8}$ of an inch thick, 6 inches long by 1 inch wide, must be cut out and squared up. One of these, which we shall for the future call the 'back bearing,' and which must be made to fit that end of the dynamo at which the driving wheel is to be placed, and which we shall henceforward call the 'back' of the dynamo, is to be bent four times at right angles, as shown at Fig. 24, *a*, where the dimensions are given. In order not to crack the brass while bending to shape, it will be well, after having given the general form by bending gently and gradually over the jaws of a vice, to heat the bends over the flame of a spirit-lamp until nearly red hot, and then to hammer up more exactly to shape, repeating the heating after each hammering until the desired sharpness of outline has been obtained.

When this object has been attained, another almost similar bearing is formed out of the remaining piece of sheet brass, the principal difference being that, as this is to be the front bearing, between which the commutator will have to turn, a much greater depth must be given to the central bent portion, as may be seen at Fig. 24, *b*, the dimensions being given in inches as before. When the brass has been bent to these forms, the bearings thus produced should be laid each against its own respective end of the dynamo, in such a position that the centre of the bend comes in the centre of the channel, the two flat extensions lying close to, and flat against, the slotted lugs shown at Fig. 23, *d*, *d*. The

bearings should now be cut in a sloping fashion to follow the outline of the lugs, as shown at Fig. 24, *c*; but the outline of the slotted portion should not be followed, as a $\frac{1}{4}$ -inch hole must be drilled in the brass at this point to take a 5-inch bolt and nut. The exact position of these holes may be obtained by holding each bearing in succession against its own proper extremity, and scratching with a steel point on to the brass the position in which the slots in the lugs fall; then, with an Archimedean drill, a $\frac{1}{4}$ -inch hole can be drilled at each extremity *nearest to the centre* of the bearing, as shown at Fig. 24, *d*.

Having got so far, let us clamp the back bearing in its place by means of two bolts about 5 inches long, passing through the holes in the bearings and through the slots in the lugs, held in their places by two nuts screwed down on to the front lugs of the dynamo. Taking the armature in one hand, we roll, as before, *one fold* of paper round it, and put a dot of Brunswick black on the extremity of the trunnion rod at the back end of the armature (the end where the holes are bored for the wire to come out is the front, the other is the back), and then insert it into the channel between the legs of the field-magnets, until the trunnion rod on shaft touches the brass forming the back bearing. In so doing it will leave a mark of Brunswick black, which will be the point at which a $\frac{1}{4}$ -inch hole must be bored. This must be done most carefully, so as to preserve centricity; and when done must be rimed out and bushed with a piece of brass tubing of about $\frac{5}{16}$ external diameter, the internal diameter of which must exactly correspond with the external diameter of the driving-shaft or trunnion of the armature; in fact, this latter must fit exactly into the tube, without any shake. This piece of tubing should be about $1\frac{1}{4}$ inches in length, and should be soldered into the central hole in the back bearing, and should extend inwards to such a degree that when the back bearing is clamped in its place, with the armature in its position, with the back trunnion in the tube, and the back head flush with the back of the magnets, it should just rest against the back head of the armature.

In a precisely similar manner the centre of the front bearing is found; that is to say, the back bearing being removed, the front bearing is clamped to the front of the dynamo, the armature,

rolled in one fold of paper, is inserted from the back end of the dynamo, front end forwards, and care taken to moisten the front end of the driving-shaft with Brunswick black or other colour, so as to get a mark where it touches. The hole being drilled and rimed out, as in the previous case, is to be likewise bushed with the same kind of brass tubing ; but, in the front bearing, the tube should be only flush with the inside of the bearing, and *should not* extend in towards the armature.

§ 26. The *Commutator* next claims our care. This essential piece of apparatus serves, as the student may remember (§ 12), to rectify, or send in one direction, the vibrations or currents which are produced in opposite directions, as each pole of the armature passes alternately before the north and south pole of the field-magnets. In screwing the brass heads down to the armature, the student was advised (§ 23, Fig. 20) to employ cheese-headed screws, projecting about $\frac{3}{16}$ of an inch above the level of the discs. The use of the projecting heads is to prevent the commutator slipping round the axis or trunnion of the armature when the latter revolves. The body of the commutator may be turned up out of a piece of sound boxwood, which previous to turning up should have been allowed to soak for a couple of hours in melted paraffin. It should, when finished, present the appearance shown at Fig. 25, *a*. While on the lathe, a hole, perfectly central, should be drilled right through it, into which the front shaft or trunnion of the armature fits tightly. The length of this should be $\frac{31}{32}$ of an inch, so that it just clears the front bearing when in its place. The diameter should be about $\frac{7}{8}$ of an inch, so that the two flat-headed screws of the front armature head should be covered by the cylinder on opposite sides of its circumference to the extent of about $\frac{1}{8}$ of an inch. Two semicircular nicks must be cut out of the bottom of the cylinder to allow these screw heads to enter, so that the cylinder when driven home rests quite against the disc or head. The front of this cylinder (the part farthest from the disc) must be rounded slightly, so as not to present too great a surface for friction against the front bearing. A piece of brass tube, $\frac{1}{8}$ of an inch shorter than the cylinder, and of such internal diameter as to fit tightly on it, is now cleaned up and cut into two exactly equal halves longitudinally. The cuts

must not be quite parallel to the axis of the cylinder, but must make a small angle with it, in order that the 'brush' or spring which takes the current off the commutator should at no time abruptly leave one half tube before it rests on the other; otherwise the commutator sparks badly while at work, and the sparks injure both commutator and brushes, besides entailing loss of current. The amount of angular deviation from the line of axis should not, in this machine, exceed two or three degrees of arc, and care must be taken they are equi-distant, and both inclined in the same direction. To insure this, stand the tube (already cut to length and cleaned) on one end. Take the exact diameter with a pair of compasses, and strike out on a piece of card a circle of exactly similar diameter. Rule two fine lines across this circle, both cutting the centre, but exactly $\frac{1}{8}$ of an inch apart at the circumference, like a letter X. Lay this card on the top of a tube, and with a steel point or file make a mark on the rim of the tube at each of the points where the lines touch the circumference of the circle. Now lay the tube on its side, and draw four lines straight along the length of the tube, starting from the points just marked. Each opposite pair of lines will be exactly $\frac{1}{8}$ of an inch apart, and quite parallel. Having done this, bring one pair of lines uppermost, and draw a diagonal line from the top of the right hand to the bottom of the left-hand line. Now turn the tube half a revolution, so as to bring the lower pair of lines uppermost, and draw a similar diagonal line, in the same direction—viz., from the top of the right-hand line to the bottom of the left-hand line. Now, with a fine hacksaw cut the tube into two halves in the direction of the two diagonal lines just described. The tube, with the diagonal lines marked ready for cutting, is shown, as if transparent, at Fig. 25, *b*. It will be noticed that though, when seen *through*, these lines cross each other, yet when either portion of the marked tube is uppermost, the line of division is from right downwards to left. The split tube is now to be fastened to the boxwood cylinder in such a position that the middles of the lines of division shall be exactly in a line with the middle of the channel of the armature. (See Fig. 26.) These two half-tubes may be attached to the boxwood cylinder or core by means of two short flat-headed screws, care being taken that

these screws do not reach to make contact with the trunnion or touch the 'head' of the armature. The split ring, when fastened in its place, should reach to within about $\frac{1}{16}$ of an inch of each end of the boxwood core; and if screws are used to fasten it down, these should be placed at the end nearer the armature. But another very neat and effective way of attaching the split tube or ring to the core is by means of two narrow ivory or bone rings, forced over the split tube, one at each end. Care must be taken, in either case, that the divisions in the split tube are maintained; for, of course, if the two halves of the tube were allowed to touch at any point, the current would flow round at that point or 'short-circuit,' and no current would be perceptible on the outside. To insure the distance being maintained, it is well to place a shaving of paraffined wood of the same thickness as the sawcuts between the two halves of the split tube on both sides.

§ 27. Those who have not a lathe can make a very fair substitute for the boxwood cylinder by rolling and gluing a stout piece of brown paper, just as if making a rocket-case, around a piece of the same iron rod that served for the trunnions of the armature, until a cylinder $\frac{7}{8}$ of an inch thick and $\frac{3}{32}$ of an inch long has been produced. This should be rolled very hard while on the iron rod, so as to insure its being truly cylindrical; the rod on which it was rolled should then be pulled out, and the tube allowed to dry thoroughly. When dry, it should be soaked for half an hour in melted paraffin, then reared on end to drain and cool. It will be found to work extremely well. Of course the split ring can be attached to this, either by screws or by two rings, as in the former case.

§ 28. Two rectangular pieces of boxwood (previously boiled in paraffin) must now be cut, planed, and drilled. These are the 'brush blocks,' which serve to support the metallic springs or 'brushes' which press against the commutator. Some operators prefer to mount their blocks on the stand, separate from the dynamo castings; here, the plan followed is to cause the bolts which clamp the bearings to the field-magnets to carry the brush blocks. To this end, the two pieces of boxwood should be cut so as to fit exactly the space left between the shoulders of the front bearings *on the outside*, and bored so as to allow the bolts to come

Fig. 25.

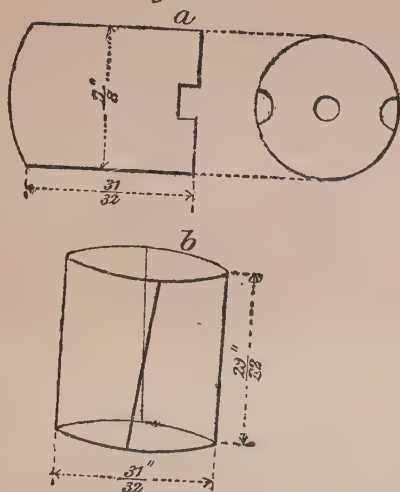


Fig. 26.

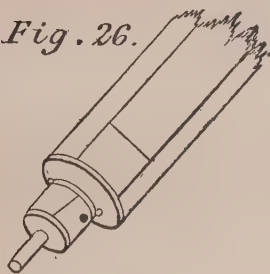
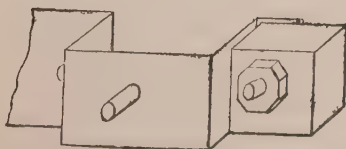


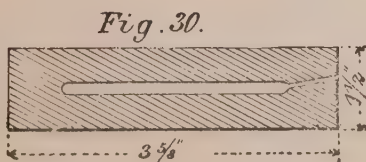
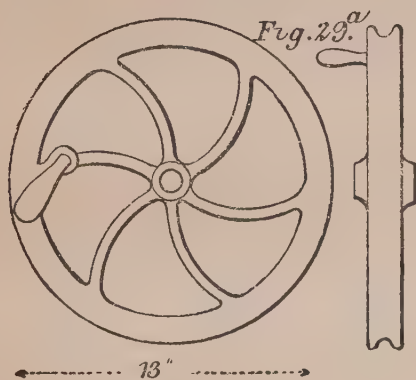
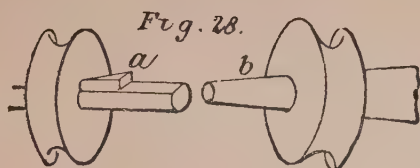
Fig. 27.



right through to take the nuts; that is to say, the blocks will be almost cubical in shape, being 1 inch long, $\frac{1}{8}$ of an inch wide, by $\frac{3}{4}$ of an inch thick. Fig. 27 shows one of these blocks in its place, clamped to the bearing by the nut and bolt.

§ 29. In order to communicate the motion from the flywheel to the armature, a small pulley-wheel, either of iron or brass, is fitted to the back trunnion, just outside the bearing. Such a pulley-wheel may be bought at any ironmonger's, and should be about $1\frac{1}{4}$ inches in diameter, and rather over $\frac{1}{4}$ of an inch thick, with the central hole somewhat smaller than the diameter of the rod which serves for the armature trunnion. This may be attached to the trunnion in either of the two following ways: 1st. By 'keying,' which consists in filing the trunnion along its length, in one direction only, so as to produce a flattened side; then, having with a rat's tail file cleaned out the central hole of the pulley to such an extent that the said trunnion will only just enter, to deepen one side (corresponding to the flattened side of the trunnion) so as to admit of a small steel wedge or 'key' being inserted. (See Fig. 28, *a*.) 2nd. By filing the trunnion-rod to a slightly conical shape, and producing a similar 'coning' in the interior of the pulley hole, which may then be driven on. (See Fig. 28, *b*, where the 'coning' of the trunnion is exaggerated, to render this mode of attachment more plainly visible.) Which-ever mode of attachment is adopted, one precaution must be taken—viz., that the distance between the back of the field-magnets and the pulley should not be *less* than $1\frac{1}{4}$ inches; otherwise, when the limbs of magnets are wound with wire, the fly-wheel will run too close to them to be altogether safe.

§ 30. The flywheel which gives motion to the armature should be a pretty heavy wheel, about 13 inches in diameter, with a groove in the rim to take the band which drives the pulley, furnished with a wooden handle for convenience of rotating. Such wheels may be obtained ready made in cast-iron, from most ironmongers, as they are sent out with 'rotary blowers,' 'portable forges,' etc. Fig. 29*a* gives an idea of the kind of wheel necessary, on a scale of $1\frac{1}{2}$ inches to the foot. The central hole is turned, and only requires fitting with an iron pin, on which it turns. Since the aperture in these wheels is about $\frac{3}{4}$ of an inch in



diameter, the pin must be filed down to $\frac{1}{2}$ an inch diameter, where it has to fit the hole in the flange at the top of the dynamo.

The farthest end should have a rounded head, to prevent the wheel from working off, while the portion which passes into the eye at the top of the flange must have a thread put on it, so as to take a nut. (See Fig. 29, *b*.)

§ 31. All the portions of the dynamo being now fitted, they should be marked so as to insure putting together again in right order after winding. When this has been done, the limbs of the field-magnets, at all parts except the channel for the armature, and the inner face of the semicircular top which rests against the wheel bracket, should receive a coat of good Brunswick-black, allowing them to dry between each application, in a warm oven. The bracket should likewise receive a coat or two of the same varnish, except where the semicircular tops clinch it. This portion *must* be left metallic, so as to ensure magnetic contact; otherwise much magnetic power is lost. Two strips of silk (colour immaterial) 10 inches long by $3\frac{1}{4}$ inches wide, should now be quickly brushed over with Brunswick-black, and wrapped, while still sticky, one round the one limb, and the other round the other limb of the field-magnets, in the space between the armature channel and the bend at the top. (See Fig. 15, where the portions indicated are marked respectively 4" and $3\frac{1}{4}$ ".) The object of this silk wrapping is to insulate the wire thoroughly from the iron, and to prevent any accidental abrasion of the covering wire, which may take place during *careless* winding from short-circuiting to the iron below. When the silk has been laid smoothly and tightly on, the limbs may be returned to the oven, and allowed to dry at a gentle heat. In precisely the same manner, the interior faces and their central portion of the armature (technically known as the 'web') must be varnished with Brunswick-black, and wrapped with one layer of similarly-prepared silk. Three pieces will be required to do this effectually—viz., two pieces $3\frac{5}{8}$ inches long by $1\frac{1}{2}$ inches wide, shaped as in Fig. 30, to fit against the inner faces, and one piece 6 inches long, by $\frac{3}{4}$ of an inch wide, to wrap round the web. Particular care must be taken that every portion of the inside of the armature's

channel be entirely covered in silk. When this has been satisfactorily performed, another coat of Brunswick-black may be given (avoiding to soil the outside), and the armature allowed to dry thoroughly in a warm oven.

§ 32. Our dynamo is now ready for wiring. For this purpose we shall require about 7 lb. of No. 16 single cotton-covered copper wire for the field-magnets, and about $\frac{1}{2}$ lb. No. 20 double cotton-covered for the armature. The amateur should be careful to get *new* wire, of the highest conductivity, and very soft; the employment of old, kinky, and hard wire is fatal to success.

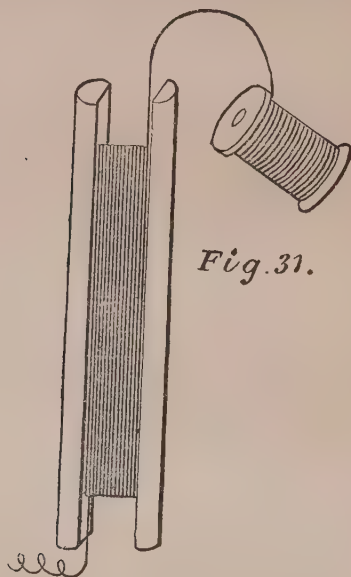
§ 33. The quantity of wire above mentioned having been duly selected, it should be tested for continuity. The No. 16 will give evidence to the sight alone, whether there be any break in it or not. Should there be such, the covering from the two broken ends should be uncovered for about an inch on each end, the two extremities filed down to a fine flat wedge, so as to fit one another, when each one separately should be warmed for a second over the flame of a spirit-lamp, dipped into powdered resin, and rubbed, while being held in the flame of the lamp, with a rod of solder, until each has taken a good coating of solder. The two ends may then be applied with their flattened portions together over the flame of the spirit-lamp until the solder coating melts. Keeping the ends pressed together, the wire is to be removed from the flame. The solder soon hardens, and the wires will be found firmly united. It is now only necessary to file away any roughness, and rewind the cotton covering over the bared portion, adding a little darning-cotton if the covering be deficient. The finer wire, which is generally bought on reels, had better be tested with the galvanometer (Fig. 2). To this end, find the two extremities of the wire, attach one to one binding-screw of the galvanometer, the other extremity being in good metallic contact with the pole of any single-cell battery. Connect the other pole of the battery with the other binding-screw of the galvanometer. An immediate and large deflection of the needle will show that the wire is continuous. If not, the wire must be unwound from the reel, and carefully wound on to another until the point at which the break occurs has been discovered. The two broken ends may be joined as described above, great care being taken

after joining to re-cover the point of junction thoroughly, so as to preclude all danger of leakage, more cotton being used to this end if necessary. It having been ascertained that the wire is perfect and in good condition, the next step is to soak it in melted paraffin wax. The good effect of this is twofold : (a) The insulation is thereby rendered very much better ; (b) a damp atmosphere has then little or no effect on the insulation, since the paraffined cotton or silk covering is no longer hygroscopic, and may actually be pumped upon without becoming wetted or spoiling the insulation. To paraffin nicely the wire should be laid in a shallow dish large enough to contain it easily—a circular tin baking dish will do admirably. It should then be placed in a warm oven, not too hot, until it is about the heat of the hand—say, 90° Fahr. About $\frac{1}{2}$ lb. of good paraffin wax should now be placed in the tin, and the oven closed until the paraffin is all melted. The wire may then be turned over two or three times until it is seen to be thoroughly soaked with the paraffin. Two or three metal rods should now be placed across the top of the dish, on which the wire may be placed to drain for a few seconds while still in the oven. When it ceases to drip it may be removed from the oven and allowed to cool. The superfluous paraffin, while still hot, may be poured into a cup (which has been just previously breathed into) to set, when it may be used for other insulations.

§ 34. Winding the armature next claims our attention. Having marked the heads, so as to know which belongs to a given extremity of the armature, we unscrew and remove them ; about 6 inches of the extremity of the No. 20 wire should be coiled tightly round the end of a pencil, so as to form a tight helix from which the pencil must then be slipped out. This helix will form one of the spare ends of the wire which will be attached to the commutator, and should be, *pro tempore*, tied with a bit of silk to the outside of the armature, so as to be out of the way while winding. Holding the armature in the left hand, with the end which corresponds to the commutator facing us, and beginning at the left-hand cheek, we wind the wire in the channel, continuing to wind until we reach the right-hand cheek, taking care to lay the wire on as closely as possible, never allowing it to ride over

its neighbour, nor yet to leave gaps between. When one layer has thus been carefully wound on, as shown at Fig. 31, it should be tested for insulation, since the amateur is very apt to wind carelessly and cut the insulating covering, either by catching in the sharp corners of the channel or otherwise. To test for insulation, tie the end of the wire (without detaching it from the reel or hank) against one cheek of the armature, to prevent its unwinding during the trial; then connect one pole of a battery to one binding-screw of a galvanometer, and the helix end of the wound wire to the other binding-screw. On touching the iron of the armature at any point with the other pole of the battery, *no deflection of the needle should take place*. Should a deflection show itself, evincing a metallic contact and want of insulation at some point, the wire must be unwound, the flaw localized and remedied by a fresh covering of cotton, basted with paraffin, and again wound on and tested until the insulation is satisfactory. A layer of thin paraffined paper should now be laid over the first layer of wire, and the winding proceeded with in exactly similar manner, until the second layer has been laid on, remembering that the essentials of success are to wind the wire as closely as possible in each layer without overlapping; to avoid grazing the covering of the wire, so as to maintain insulation, and to wind always in one direction—viz., *from us, over to under*. There is no necessity (when using well-covered wire) to place a stratum of paraffined paper between each layer of wire, as this, by increasing the distance between the layers, somewhat decreases the efficiency of the machine: this is only advisable when the insulation of the wire has been found to be imperfect. The winding should be proceeded with, layer after layer, evenly, tightly, and smoothly, until the wire just fills the channel. Care must be taken that it does not exceed this, for if it comes higher than the cheeks it will surely catch in the limbs of the field-magnets during rotation. From eight to nine layers of wire may be laid on, according to the tightness with which it is pulled during winding. When the due proportion of wire has been laid on, it should be fastened down by tying, so as not to unwind, with its free end at the same extremity (the commutator end) as we started from. The helix may now be straightened out, and its condition observed, to insure that it is well insulated.

The end at which we finished winding should also be straightened out and examined for good covering. Then a stick of Prout's elastic glue should be heated and rubbed over the covered ends right up to the armature, so as to thicken them to such an extent that they will only just pass through the holes bored in the head to which the commutator is attached. (See Fig. 19, c, c.) The wire ends should be passed one through each of these holes (care being taken that the head be put on as it was previous to removal),

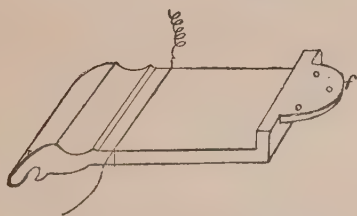
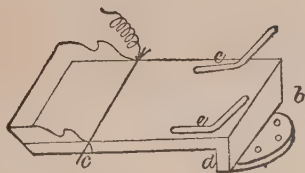
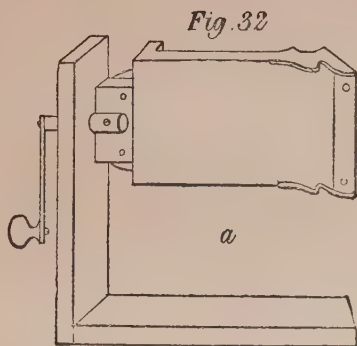
*Fig. 31.*

pulled pretty tightly, but not so roughly as to graze or injure the covering, and having been cut so as to just reach the heads of the screws, which fasten the two halves of the split tube of the commutator to its cylinder (see Fig. 26), should have their extreme ends unwound and cleaned, and then be soldered down, one to each half of the split tube, care being taken that neither the solder nor the wire passes beyond the line of the screws, so as to leave plenty of room for the brushes to press against the commutator. The heads may now be screwed up in their place, and a

coat of good sealing-wax varnish (best made by dissolving good scarlet sealing-wax in methylated spirit) painted over the layers of wire, both for the sake of appearance and to keep the wires from moving out of place during rotation, though if the wires are tightly wound this will be hardly needful. This coat of varnish must be allowed to dry off in a warm atmosphere (not in the oven), and the armature will be complete.

§ 35. Our labours are now drawing to a close. To wind the field-magnets it will be as well to rig up a little piece of apparatus, since, although they may be wound without, it is very difficult to lay the wire as closely, as tightly, and as neatly as can be done by its aid; and since the efficiency of the machine is greatly exalted by the greater proximity of the wire to the core, it is a matter of considerable importance that this should be attended to. The apparatus necessary consists of a handle fastened to an axle passing through a standard supported on a base; the axle having a prolongation to which each limb of the field-magnets can be screwed down in its turn. On turning the handle, it is evident that the iron mass of the field-magnet will rotate on its axis, and if care be taken that the centre of the mass coincides with the centre of motion, the motion imparted to the iron will be smooth and even, and the wire may be laid on with great exactitude and closeness. This apparatus is illustrated at Fig. 32, *a*, with one of the limbs of the field-magnets screwed in its place, ready for winding. It should be made out of $\frac{3}{4}$ -inch stuff, the base being about 5 inches wide by 6 inches long. The upright through which the axle passes should also be about the same size, and screwed to the edge of the base-board, so as to stand at right angles to it. A short piece of broomstick, about $\frac{3}{4}$ of an inch in diameter, may be used as the axle, and a hole must be bored in the upright, at about 4 inches from this base, to admit this axle. To the external portion of the axle is fastened a handle; while to the internal portion, which should protrude about $1\frac{1}{2}$ inches, is screwed a piece of $\frac{1}{2}$ -inch stuff about $1\frac{1}{2}$ inches square, half the axle being cut away to admit of its lying flat. Previous to screwing down, the handle, as well as this latter square piece, should be rubbed over with a little good hot glue at the places where they touch the axle, to insure a good sound joint. This

'winder' being completed, it may be clamped to a bench or table by means of a sewing-machine or fretsaw clamp, the leg of the field-magnet having been previously screwed to it by means of the three holes in the flange, in the position shown in the figure. Though shown in the cut to the *left*, the handle of the winder should be to the *right* of the operator, unless he be left-handed. In commencing to wind the wire, the operator should stand over his work, a sheet of paper having been placed on the floor, and the coil of paraffined wire at his feet, with a two-gallon stone bottle filled with water in the centre of the coil to prevent its entangling or kinking. The surface of this jar being glazed, the wire slips from it without injuring the covering. The winding should be commenced at the extremity farthest from the handle—*id est*, nearest to the *channel* in the field-magnets in which the armature rotates. Six or eight inches of the wire should be coiled round a pencil, and so as to form a tight helix, which, with a piece of strong twine, should be tied to the leg of the magnet, as shown in Fig. 32, *b*. Holding the loose end of the wire in the left hand, keeping it pretty tightly pulled, and straightening it out from its coiled shape as it passes through the fingers, it is easy in this manner to wind the wire perfectly flat and smooth by turning the handle of the winder in the direction of the motion of the hands of a watch. (In order to prevent any accidental contact through abrasion against the corners, etc., it is advisable previously to cover the legs of the field-magnets, at all events as far as the wire is to extend—viz., from *c* to *d* in the present figure—with a band of silk dipped in melted paraffin, and applied hot to the iron, when it will immediately adhere. This band must be carefully smoothed down, so as not to cause unevenness in the winding of the wire.) If the wire be nicely laid on, it will be found possible to wind forty rows between *c* and *d*. Before arriving at *d* it will be necessary to place two pieces of tape about $\frac{1}{2}$ an inch wide and 3 inches long, as shown at *ee* in the figure, the free ends of which must be turned back smoothly and tightly over the layer just put on when *d* is reached. Continuing the rotation of the handle in the same direction, another layer of wire is now laid over the first; by holding the ends of the tape fast while beginning to wind this second layer, all tendency of



ARRANGEMENTS FOR WINDING THE FIELD-MAGNET.—*a*, The winder, with one limb of the field-magnet in position; *b*, Position of wire on starting the right limb; *c*, The wire; *d*, The flange; *e*, The tapes; *f*, Position of wire on starting the left limb.

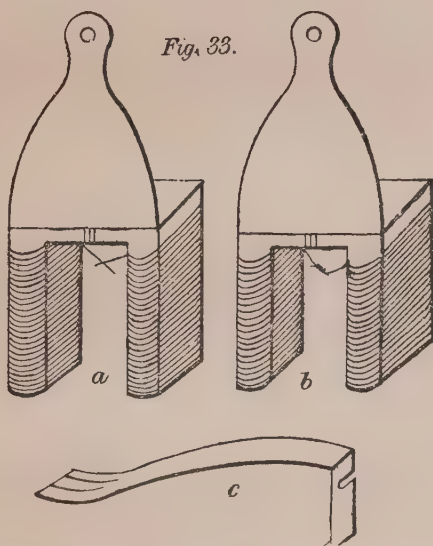
sinking into the layer beneath, which may be displayed by the second layer, is overcome. Without this precaution it is almost impossible to prevent the outer layers of wire sinking into the interspaces of the layers below. Continuing in this manner, layer after layer should be laid on until seven layers have been wound, remembering to use tapes towards the end of each layer, and that each layer will diminish by two rows. When the seven layers have been laid on, the wire must be tied down to the magnet to prevent uncoiling, and cut off from the hank of wire, leaving about 6 inches free for attachment.

In exactly a similar manner as regards attachment, direction of winding, etc., must the second limb be wound. The only difference that need be made is that, for convenience of having both ends of wire at the same end of the dynamo, it will be well to fasten the beginning of the wire (the helix) to the inside of the leg instead of to the outside. Fig. 32, *f*, will make this clear.

§ 36. Both for the sake of appearance and to further protect the insulation from damp air, etc., it is advisable to give the wires on the limbs of the field-magnets a coat of good varnish. The best for this purpose is made by mixing about 2 ounces of the best red lead with $\frac{1}{2}$ an ounce of good *white hard* varnish, which can be procured of any oilman. The two should be well incorporated together by working with the brush intended to be used for laying on the varnish.

The varnish should be applied in a thin layer with a soft brush, so as to disturb the paraffin coating as little as possible, since if the paraffin mixes with the varnish, this latter *never dries*, but remains a sticky mess. For this reason the coating of varnish should be allowed to dry without the application of heat, which, if the 'white hard' be good, it will do in about eight to twelve hours. A second coat may be given if desired; but as this generally fills up the interstices between the layers of wire, it detracts somewhat from the neatness of the appearance.

§ 37. The varnish being *quite dry*, the dynamo may again be put together, care being taken that the parts are adjusted in the position which they occupied after fitting. If this has been properly done, the armature ought to turn freely in its bearings *quite close* to the limbs of the field-magnets, but without catching any where.



ATTACHMENT OF WIRES AT UPPER PORTION OF THE FIELD-MAGNET.—
a, Wires cleaned and uncovered ready for joining ; *b*, Wires twisted and soldered ; *c*, Brass spring, or 'brush,' to collect the electricity from the commutator.

Supposing this to be all right (and it must be so, or the dynamo cannot work properly), the dynamo must be screwed down to a base-board, which should consist of a slab of oak, walnut, or mahogany, 10 inches long by 8 inches wide, and at least 1 inch thick. The two holes in the lower flange in the limb of the field-magnets, near the channel in which the armature revolves, are expressly for the purpose of clamping the dynamo to its base-board. The base-board should be chosen of a well-seasoned nature—polished, for appearance' sake; and the dynamo should be screwed to it centrally, with the narrowest portion of the dynamo parallel with the narrowest portion of the baseboard.

ATTACHMENT OF THE WIRES.

§ 38. The dynamo having been wound as described (and care must be taken to have fulfilled the instructions exactly, or else the resulting magnet will have two *north* poles, or two *south* poles, instead of one north and one south), we can proceed to couple up the various parts. To this end we begin by joining the wires at the two extremities at which we *left off winding*. This may be effected by removing a portion of the covering of the wires (by scraping with a sharp knife) for about an inch along the places where the two wires cross each other if made to touch. (See Fig. 33, *a*.)

The wire must be made quite bright and clean by rubbing with a bit of sandpaper at this point, and then the wires are twisted tightly together by the aid of a pair of pincers. A drop of solder, taken up on a hot soldering-iron and run along the twisted portion will insure the contact remaining good. The excess of wire should now be cut off from the twisted end with a pair of cutting pliers; the bared twist bound round with a layer of darning-cotton, varnished with the red varnish (§ 36), and turned in out of the way between the limbs of the magnet. (Fig. 33, *b*.)

We may now proceed to magnetize the field-magnets. For this purpose we need only attach the poles of a single-cell bichromate battery, exposing from 8 to 10 square inches of negative surface, to the wires of the dynamo for a few seconds; but in order to obtain results which may be deducible from reason, and which

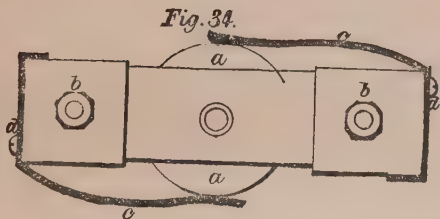


Fig. 35^a

Fig. 35^b



THE BRUSHES AND BRUSH BLOCKS.—Fig. 34.—*a a*, The commutator. *b b*, Brush blocks. *c c*, The brushes. *d d*, Screws to tighten up the brushes.

Fig. 35 *a*.—Wire loop to connect brushes with binding-screws.

Fig. 35 *b* —The same in position on the brush-block.

can be corrected if mistakes are made, it is desirable to determine beforehand which shall be the north pole of our future magnet. It will be remembered (§ 8) that we have it in our power to produce a north pole, *to our left*, in a mass of iron, by passing a current of electricity *away* from us, *over it*; and if we wish to produce a north pole to the *right*, the current must come *towards* us, over the mass.

Let us decide to make a north pole of the limb on which we began to wind the wire on the *outside*. (See Fig. 32, *c*.) To do this the current ought evidently to flow *from* the limb of the magnet to the observer; in other words, this wire must be attached to the negative pole of the cell. (The negative pole of the bichromate cell is the wire proceeding from the zinc, the one attached to the graphite being positive.) The positive pole of the cell must be coupled to the other wire—*id est*, the one which was started from the *inside* in winding. (See Fig. 32, *f*.)

While the battery is thus coupled up to the dynamo, we can test if we have produced the effect desired by bringing a suspended magnetized needle near the supposed north pole of the dynamo. If all has been properly performed, it will be found to attract the south pole of the poised needle, and repel its north pole.

A few seconds' connection with the battery will impart as much magnetism to the field-magnet as it will retain; but that little will be sufficient for our purpose. Our next step is to discover in which direction the current flows in our armature, when we rotate the flywheel in the usual way with the right hand (in the direction of the motion of the hands of a clock). Before we can do this we must fasten two 'brushes' or collectors on the brush-blocks, in order to collect the electricity generated by the revolution of the armature.

THE BRUSHES.

§ 39. These consist of two pieces of springy sheet brass, $\frac{1}{32}$ of an inch thick, $3\frac{1}{4}$ inches long, and about $\frac{5}{8}$ of an inch wide. They must be bent twice at right angles, so as to fit tightly on to the brush-blocks (§ 28, Fig. 27), and slightly curved inwards at the longer portion, so as to press with some force against the com-

mutator. (See Fig. 33, *c*.) To fasten these on to the blocks, a lateral slot is cut about half-way into each brush, at about $\frac{1}{3}$ of an inch from the longest portion, of such a width as to admit the shank of a small screw passing into it. The portion of the brush which rests against the armature should be slit into two or three divisions, and curved slightly upwards to avoid scratching the armature.

These two brushes, though alike in shape, must be put in opposite positions on the dynamo ; that is to say, the one which goes on the block to the right of the observer has the longer portion above the block, while the one which goes on the left-hand block has the longer portion below the block. Thus the commutator is rubbed by these two brushes at diametrically opposite points. Care must be taken that the two screws which serve to fasten the brushes to the blocks do not touch the metal of the bolts which clamp the bearings to the dynamo, for if they did the current would short-circuit, and the machine would not work. It will also be necessary to observe that sufficient curvature be given to the longer portion of the brushes to clear the bearings altogether, otherwise, of course, the current would pass into the bearings and be short-circuited. Fig. 34 shows the brushes in their proper position ; *a, a* being the commutator (exaggerated in size somewhat to show its position), *b, b* the brush-blocks, *c, c* the brushes, and *d, d* the screws which, by being tightened or loosened, can increase or decrease the pressure of the springs on the commutator, and to which the two wires which form the electrodes of the commutator are to be attached. These two wires, which in our machine may be about 3 inches long, with a loop at each end, as shown at Fig. 35*a*, should be of No. 16 cotton-covered copper wire, the covering being removed from the two loops, which must be made quite bright. Before putting in the screws *d, d*, Fig. 34, each one should be passed into one eye of one of the said wires, then screwed partly into the brush-block, when the brush itself may be pushed into its place over the block, and under the screw, the slot in the side admitting of this ; lastly, the screw is tightened up until the desired pressure on the commutator is obtained.

Fig. 35*b* shows the position of the wire, screw, and left-hand

brush on the left-hand block. The two free ends of the wires just described project straight forward to the front of the machine; they may be screwed down on the baseboard, at the distance of about 3 inches apart, by means of a small pair of binding screws; the long screws of which are passed through the free eyes.

We can now test the direction of the current in our armature. To do this we place the flywheel on its bracket, put a leather band (such as is used for treadle-sewing-machines) round the flywheel and driving pulley, then by means of two thin wires, which we will screw into the holes of the binding-screws just

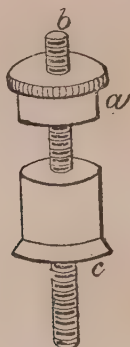


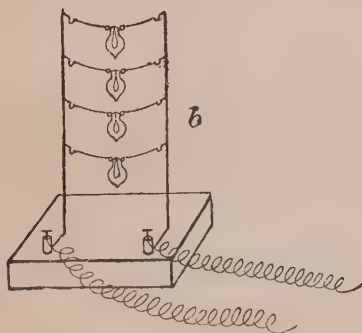
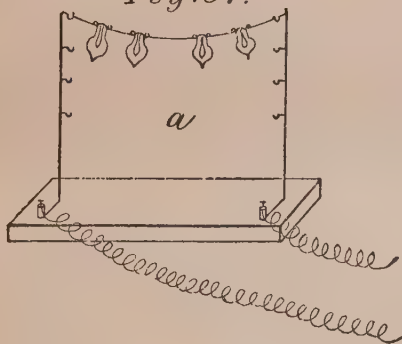
Fig. 36.

arranged, we couple up the brushes to our galvanometer (§ 3), and rotate the handle of the flywheel gently, in the direction we intend to work the machine for the future.

A deflection of the north pole of the needle, either to right or left, shows us in which direction the current is travelling; we carefully note, and mark with a paper label, which is the binding-screw which is sending the positive current (which, if coupled to the wire *over* the needle, causes the north pole to turn to the left), since this is the binding-screw which must substitute the positive pole of the battery, and to which we must attach the wire which comes from the S limb of our dynamo.

§ 40. Two binding-screws are now to be inserted into the base-

Fig. 37.



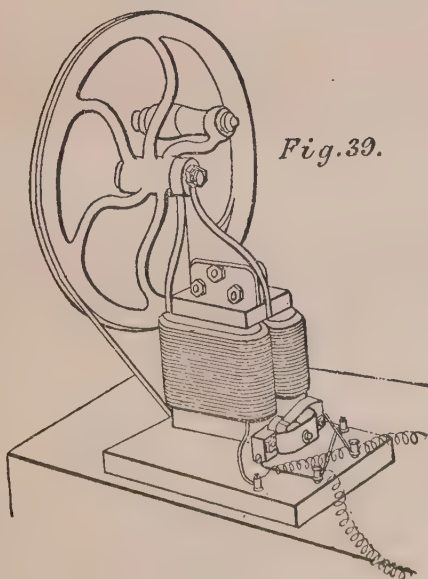
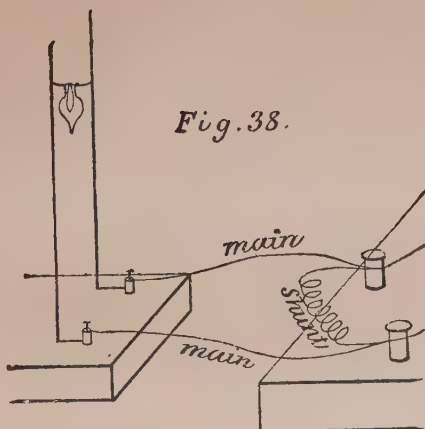
MODES OF ATTACHING LAMPS.—*a*, For series. *b*, For parallel arc.

board, to which the wires proceeding from the limbs of the field-magnet must be clamped. These should be placed about $1\frac{1}{2}$ inches from the side of each limb, the wires proceeding therefrom being denuded of their covering and sandpapered at the extremities where they are clamped to the binding-screws. These binding-screws (as also those connected with the brushes) should, for the convenience of being able to couple up at one and the same time two or more wires, be of the pattern shown at Fig. 36, in which case the extremities of the field-magnets may be also formed into rings, as shown at Fig. 35*a*, and either clamped down to the base-board by passing the long screw *c* (Fig. 35) into the ring, or, the nut *a* having been removed *pro tem.*, the ring may be slipped over the screw *b*, and then clamped by the nut *a*.

Connection is now to be made between the binding-screw attached to the current-sending or positive brush (the one which we have marked with a paper label), and the binding-screw coupled to the wire, starting from the *inside* of the limb of the field-magnet (see Fig. 32, *c*) by means of a short length of No. 16 copper wire, well cleaned, bent into rings at the ends, and clamped down as advised above.

If all the instructions have been carefully carried out, more especially those contained in the last six paragraphs, we shall find that on rotating the flywheel a powerful current will flow between the two remaining binding-screws—viz., the one connected with the outside wire of the field-magnets, and the other with the negative brush of the commutator—a current which will be sufficient to heat to bright redness $4\frac{1}{2}$ inches to 5 inches of No. 42 platinum wire, or to light four 5-candle power lamps, arranged in parallel arc.

The current actually flowing through the circuit (the number of amperes) will naturally depend largely on the resistance interposed between the poles—that is to say, between the binding-screws connected with the outside wire of the field-magnet, and the negative brush of the commutator respectively: and since the magnetism of the field-magnet depends entirely on the amount of current flowing around it, and this again influences the current set up in the armature, it is evident that every variation in the resistance of the interpolar or outside circuit will



produce a corresponding variation in the current, if the dynamo be connected up as above described ; and that a very much larger current will traverse the circuit when the resistance is small, than when the resistance is great. When the machine is doing its best work—that is to say, when the resistance of the interpolar is equal to the internal resistance of the machine—the current is equal to that of eight or ten Bunsen's cells against an equal resistance. Sometimes it is necessary to send the current through a greater resistance ; in this case, in order not to weaken too greatly the magnetism of the field-magnet by diminishing so greatly the current, it is necessary to shunt off a portion of the current, and send it round the limbs of the field-magnet by another circuit, which diminishes the total resistance.

To render this clearer, let us suppose that we wish to light up four 5-candle lamps, having each an approximate resistance of 15 ohms, and requiring a current of about 1 ampère each to cause them to give out their proper light. If we arrange them in series, as in Fig. 37, *a*, when the total resistance is the sum of their separate resistances = 60 ohms, then, as the electromotive force of our machine when at best is about 20 volts, so $\frac{20}{60}$ represents the current flowing through the lamps, supposing even that the dynamo lost no power by the diminution of current (which it does to a very great extent), and this current is not sufficient to light the lamps. But if we arrange the lamps in parallel arc, as at Fig. 37, *b*, then the total resistance falls to a quarter of one single lamp—that is to say, it is equal to 3.75 ohms only ; hence, the current now flowing becomes $\frac{20}{3.75} = 5.6$ ampères, and this divided among the four lamps gives 1.4 ampères each, which is ample.

Again, we find that coupling up one single lamp to the dynamo presents too great a resistance, so that no light is given off, since not sufficient current can pass round the field-magnets to give an electromotive force of 10 volts. But if we insert a 'shunt,' consisting of about a dozen inches of No. 30 iron wire, between the two binding-screws aforesaid, as shown at Fig. 38, and then connect the lamp also to the said screws or terminals, more current circulates round the field-magnets, since two roads are now open to the current, the field-magnet becomes more power

fully magnetic, and in its turn induces a much more powerful current in the armature, and so on until current enough is produced to light up the lamp. The resistance of the 'shunt' to be inserted between the terminals, to produce the best result, will depend on the resistance of the interpolar. If this latter be low, no 'shunt' (or one of very great resistance) will be required; but if the resistance of the interpolar be very high, the resistance of the 'shunt' must be correspondingly low, or else not enough current will pass to magnetize the field-magnet, and the dynamo will give no current.

Fig. 39 represents the dynamo completed.



ADDENDA.



§ 41. SERIES AND SHUNT WINDING. The machine described in the foregoing pages is wound "*in series*," and the wire put on the field magnets is of such a gauge and quantity as to allow the use of ordinary cast iron. According to Sir William Thomson, the ratio which should exist between the resistance of the wire on the armature and that on the fields is, in series machines, as $\frac{2}{3}$ to 1. As the student may be desirous of constructing other and larger machines, the following tabular statement may be found of service for *series* winding:—

Resistance of <i>outer circuit</i> , including lamps, wires, &c.	20
Resistance of armature coils	1
Resistance of field magnet coils	$\frac{2}{3}$

As to the gauge of the wire to be put on the armature, *that* must depend on the amount of current the machine will be called upon to supply, since the wire must be of such a section as to be able to carry this current without injurious heating. The following table gives the "safe-carrying capacity" of copper wires from No. 0 to No. 25 B.W.G.:—

TABLE OF SAFE-CARRYING CAPACITY OF COPPER WIRES, ETC.

Birmingham Wire Gauge.	Diameter in Inches.	Ampères of current safely carried.	Birmingham Wire Gauge.	Diameter in Inches.	Ampères of current safely carried.
No. 0	0·340	172	No. 13	0·095	13·
" 1	0·300	134	" 14	0·083	10·
" 2	0·284	120	" 15	0·072	7·
" 3	0·259	100	" 16	0·065	6·
" 4	0·238	85	" 17	0·058	5·
" 5	0·220	72	" 18	0·049	3·
" 6	0·203	61	" 19	0·042	2·
" 7	0·180	48	" 20	0·035	1·5
" 8	0·165	40	" 21	0·032	1·2
" 9	0·148	32	" 22	0·028	1·0
" 10	0·134	26	" 23	0·025	0·75
" 11	0·120	21	" 24	0·022	0·70
" 12	0·109	17	" 25	0·020	0·50

The *length* of the wire to be used on the armature (and consequently the size of the armature itself) will depend on the electro-motive force, *reckoned in volts*, which it is desired to obtain from the dynamo. At an *angular velocity** of 1250 feet per minute (and this is a convenient rate, whether for large or small armatures), it is found that every yard of *active wire* (wire that actually cuts the lines of magnetic force) will give 1 volt of electro-motive force. Hence 1 yard = 1 volt.

The size of wire to be used on the fields may roughly be taken as being four numbers lower, in B.W.G., or about twice the diameter of that used on the armature. Thus, if No. 20 be used on the armature, No. 16 should be used on the fields; or if No. 16 be used on the armature, then No. 12 will be the right size for the field magnets. Of course, if it be desired to avoid the difficulty of winding a very thick wire on the field magnets, a number of strands of a finer wire, equivalent in their totality to the coarser wire, may be employed instead, and laid on "in parallel," as shown at Fig. 40.

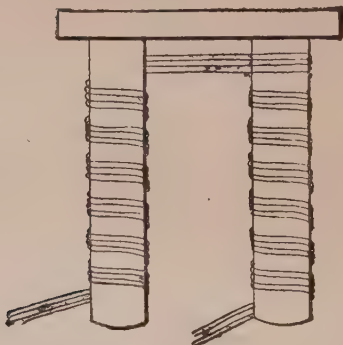


Fig. 40.

When it is desired to wind a dynamo specially as a *shunt* machine, the following proportions are found, on a large scale, to give the best

* *Angular velocity*, the rate at which a point on the circumference of a circle moves, when this latter is caused to rotate. It can be ascertained as follows: Measure the circumference of the rotating body. Multiply this by the number of revolutions per minute; the result will be the angular velocity per minute, expressed in inches, feet, or yards, according to which were used to take the measure of the circumference. For example: What is the angular velocity of an armature $1\frac{1}{2}$ inches in diameter, rotating at the rate of 3000 revolutions per minute? $1\frac{1}{2}$ inches diameter is equal to $1\frac{1}{2} + 3.14$ or about 4.71 inches in circumference. Multiplying this by 3000, we get 14,130 inches, or 1177 feet of "angular velocity" per minute.

and most economical results; they also have been deduced by Sir Wm. Thomson :—

Resistance of outer circuit	.	.	.	.	20
Resistance of armature coils	.	.	.	.	1
Resistance of field magnet coils	.	.	.	.	400

In practice, in small dynamos of from 5 to 200 c.p., it will be found that better results are obtainable when the field-magnet resistance is considerably lower than four hundred times that of the armature. And this difference makes itself more felt if the iron be at all *hard*. Wrought iron magnetises much more freely than cast iron with many turns of wire carrying a small current; while the harder iron seems to need a larger current, with fewer turns, to “start” it. For small dynamos, from 5 to 20 c.p., the relation between A. and F. Ms. may be 1 to 10 with advantage. From 20 to 50 c.p., dynamos may have 1 for A. and 50 for F. Ms.; from 50 to 100 c.p., the ratio may be as 1 to 100; and from 100 to 200 c.p., the ratio for useful work will be found to be about 1 to 200. Beyond this Sir Wm. Thomson’s rule of 1 to 400 will be found to hold good and give excellent results. At § 38 directions for magnetising the series wound machine is given; here it may be observed that with shunt wound machines a battery of higher E.M.F. will be needed to induce in the iron sufficient residual magnetism to start the machine. Thus, for instance, if the dynamo which forms the subject of the preceding sections were wound as a shunt machine, with about $2\frac{1}{2}$ to 3 lbs. No. 22 on the field magnets (the armature remaining the same), it would be found advisable to employ 5 or 6 cells of a bichromate or chromic acid battery to magnetise the field magnets to the full. The shunt dynamo is wound precisely the same as the series, with the exception of the greater fineness and increased resistance of the wire employed on the fields. The difference lies in the fact that the two ends of the wire forming the beginning and ending of the field-magnet coils are brought to, and connected with, the brushes, one on each side, as is well shown at Figs. 41 and 42, the former being an outline sketch of a *vertical*, and the latter a more finished design of a *horizontal*, form of Siemens’ dynamo.

§ 42. DYNAMOS OF OTHER FORMS. The form given to the field magnets has been varied almost *ad infinitum*, fanciful names, derived either from the individuals who designed them or the places where

they have been built, being given to the different types. With regard to the armatures, there are several distinct types, some of which seem

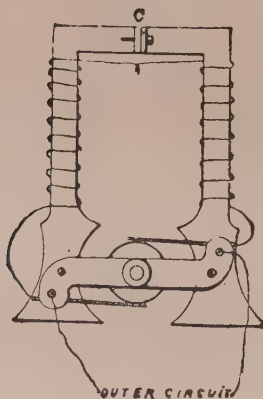


Fig. 41.

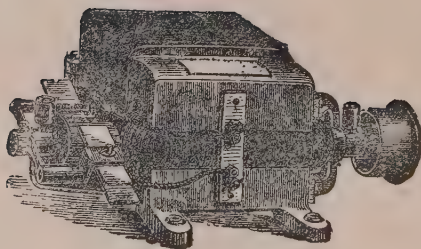


Fig. 42.

to possess certain advantages, for specific purposes. The armatures may be conveniently arranged into four great classes, viz. :—

1. *Pole* armatures, in which the wire is wound on two or more bobbins enclosing iron cores, as shown at Figs. 10 and 11.

2. *Drum* armatures, in which the wire is wound longitudinally round the length (not the circumference) of a cylindrical drum, either

of solid iron or of laminæ. Such an armature, partially wound, is illustrated at Fig. 43.

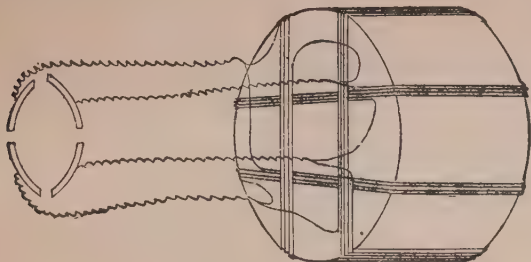


Fig. 43.

3. *Ring* armatures, of which the Pacinotti (see Fig. 13) may be taken as the type. The ring is wound longitudinally, outside and in with the wire, and may be furnished with cogs, as in Fig. 44, or be without cogs, as in Gramme's modification of the Pacinotti ring, Fig. 45. From the classical experiments of Prof. S. Thompson, we are in a position to state that the projecting teeth or cogs of the Pacinotti form of ring increase the efficiency of the dynamo from 30 to 50 per cent. It must be noted that the layers of wires lying *inside* a ring armature are almost entirely inactive, as far as the production of electro-motive force is concerned, so that, in calculating the number of yards of wire to be laid on an armature of the *ring* form, allowance must be made for these internal, and consequently inactive, coils of wire.

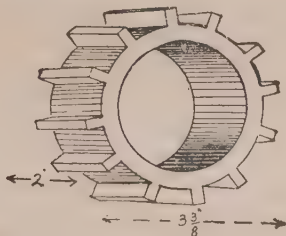


Fig. 44.

4. The *Disc* armature consists of a disc running between a circle of opposing magnetic poles, said disc being built up either of flattened coils attached to radial arms, or of radial bars connected at the outer ends by concentric hoops, and at the other by plates or washers.

Armatures of the disc form, with coils facing a circle of opposing magnets, are useful in the production of alternating currents.

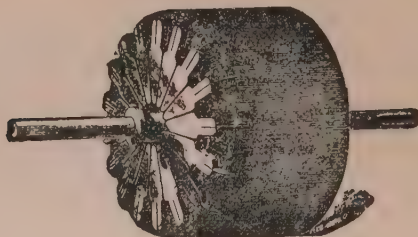


Fig. 45.

There are other forms of armature which do not fall within either of the preceding categories. One is the Thomson-Houston spherical armature, which consists of a spheroidal iron shell, around which are coiled three sections of wire, each making an angle of 120° with the one below it. These sections are connected together at their starting extremities, and are made to terminate, each one, in one of the sections of a three-part commutator or collector. So enormous is the fluctuation with this form of armature that a special device (in the form of a "blower") has been devised to blow away the sparks at the brushes.

Another extraordinary form of armature is the tuning-fork armature of Edison, in which the prongs of a huge tuning-fork (duly wound with wire) are caused to vibrate before the poles of an electro magnet.

Yet another form consists in giving a cylindrical shape to the armature, and letting it revolve round the pole of the electro magnet. In this case the armature may be an insulated cylinder of copper, and one such cylinder may surround each pole piece. Belonging to this type are the dynamos of Messrs. Siemens and Halske, M. Delafield, and Sig. Ferraris. Prof. George Forbes has also constructed a very remarkable machine of this class. But machines of these latter types are not likely to fall within the province of the amateur, so no further notice will be made of them in these pages.

It is otherwise with dynamos of the drum and ring types. The steadiness of the current given by these (see § 17) renders them specially adapted for lighting on a large scale, for electrolysis, and plating. For this reason the following constructional details of one or two forms

of dynamos, with the drum and ring form of armature, may be serviceable to the student.

§ 43. THE DRUM ARMATURE DYNAMO. Having decided upon the voltage and amount of current the dynamo is desired to give, the operator calculates, by means of a wire-gauge table, the size he must give to his drum to admit of the necessary quantity of wire being laid on. It is well to bear in mind that the diameter and length of the drum should bear the ratio of 1 to 3, or, in other words, an armature 3 inches in diameter should not exceed 9 inches in length. In order to secure the best results from the magnetism of the field magnets, it is well to keep the number of layers of wire on the armature as low as possible. One layer only is theoretically the best; practically the number should not exceed five layers. To enable the student to calculate for himself the dimensions to be given to a drum armature of any desired output, one example will be worked out. Let us suppose we desire to produce an armature, which at our normal speed (1250 feet angular velocity per minute) shall give 8 ampères, at 55 volts pressure. According to the rule laid down (§ 41), this means that we must employ about 55 yards of active wire. But since the wire which lies on the *ends* of the drum is virtually inactive, and since this amounts to about $\frac{1}{3}$ of the whole it follows that at least 82.5 yards of wire must be used, and, to allow for slack winding, &c., it will be well to employ 90 yards instead of only 82.5, so that 90 yards will be reckoned as a fair quantity for the amateur to lay on his armature to get 55 volts. As we desire to have a current of 8 ampères it is evident that the wire must be of sufficient gauge to carry such a current. But it will be noted that in the drum armature, as in the ring armature, where the coils are *continuous*, and all connected together, the current has always *two paths open to it*, one on either side of the line where the brushes take up the current. Hence, on the armature of machines of the ring and drum type, the carrying power of any given wire is double that given in the foregoing table. From the table we glean that No. 17 B.W.G. carries 5 ampères without injurious heating; therefore, this wire, on our armature, would safely carry 10 ampères. No. 17 cotton-covered copper wire can be made to lie easily 16 coils to the inch; hence it is evident that the 90 yards can be coiled easily in *two layers* lengthwise all round a drum $6\frac{3}{4}'' \times 3''$ or thereabouts; and this even allowing for the presence of cogs round the periphery of the drum to ensure the laying of the wire in sections of equal lengths and

widths.* Calling the circumference of the three-inch drum 9 inches (it is more) and allowing 16 coils to the inch, we get 72 single coils. Now, taking the amount of wire required to reach round the drum from end to end as being $7 + 3 + 7 + 3 = 20$ inches, we get $20 \times 72 = 1440$ inches, or 40 yards, as the amount of wire which would coil tightly one layer deep all round the drum. Allowing for the amateur's slack winding and for the sectional division, we shall, therefore, easily get the 90 yards *plus* the cogs or wedges that mark the divisions, in two layers on an armature of this size.

§ 44. A number of soft iron washers, such as may be procured at almost any iron-fitter's shop, 3" in diameter, about $\frac{1}{8}$ " thick, with a central hole of about 2" in diameter, is now selected. A sufficiency of these washers must be obtained to make a column about $6\frac{3}{4}$ " high, if laid one upon another. A rod of mild steel, about $\frac{5}{8}$ " diameter and 18" long, is now chosen for the shaft. A cylinder of any hard well-seasoned wood is now bored out to fit tightly over this shaft for about $7\frac{1}{4}$ " of its length in the centre. When fitted, it should be fastened to the shaft by means of a key and drift. The outside of the wooden cylinder

* It must be borne in mind that the greater the number of sections laid on an armature, the smaller will be the fluctuation in current. For instance, let us suppose an armature, capable of giving 100 units, be built up in two sections only; it will be evident that, in passing the brushes, there will be two periods in each revolution when the full current of 100 units will be obtained, and also two periods when absolutely no current will pass, or, in other words, the fluctuation will be 50 per cent. But by laying the wire on in several sections, and joining the ends of the wires to a number of commutator bars equal to the sections, we diminish the fluctuation. The annexed table shows the diminution of fluctuation caused by increasing the sections:—

TABLE OF FLUCTUATION IN CURRENT DUE TO NUMBER OF SECTIONS.

Number of Sections.	Total Fluctuation.	Percentage of Fluctuation.
2	0.5	50.00
4	0.0979	14.04
10	0.0159	2.38
12	0.0110	1.70
15	0.0070	1.10
20	0.0039	0.61
24	0.0027	0.42
30	0.0018	0.28
36	0.0012	0.19

The above table is condensed from Prof. S. P. Thompson's *Dynamo-Electric Machinery*. Avoiding the self-induction of the separate sections is also a great reason for increasing their number.

should then be turned down until the iron washers can be made to fit tightly over it. When this is the case, before putting on the washers, the operator cuts out roughly two circles in $\frac{1}{4}$ " hard wood, places them on a lathe, and turns them up to true circles 3" in diameter, with central holes that can be fitted tightly over the ends of the cylinder or "hub" that carries the washers. When these have been turned up, there must be inscribed, by means of a pair of compasses, 12 equidistant lines round the periphery of each disc. Then with a thick saw, a rather wide slot is cut in both the discs, at each of the lines, extending about $\frac{3}{8}$ " in the disc. In each of these slots is inserted a wedge or cog of hard wood, about $\frac{1}{8}$ " thick, $\frac{1}{4}$ " wide, and projecting about $\frac{1}{4}$ " above the periphery of the disc. When this has been done, one of the discs can be glued on to one end of the cylinder or "hub," and when the glue is hard and dry the washers are to be forced into their place, enough being used to make a drum (when both discs are in place) about $6\frac{3}{4}$ " in length. This being done, the other disc is glued in its place to keep the washers firm and immovable. Care must be taken at this point that the cogs of the two discs stand exactly in a line with each other.

§ 45. While the glue is drying the operator may proceed with the commutator. This resembles very closely the one described at § 26, with these points of difference:—

1. Since the armature will be wound with 12 distinct coils of wire, so there must be 12 divisions in the commutator.
2. The divisions in the brass tube or collar are not cut diagonally, but perfectly parallel with the axis of the shaft.
3. The size of the brass tube must be considerably greater.

A convenient size for such a machine as the one under consideration is made by procuring a stout brass or gun metal cylinder (this may be cast specially) about $\frac{3}{16}$ " in substance, $2\frac{1}{4}$ " external diameter, and 2" long. A piece of sound box wood of about the same size is now bored out to fit tightly on to the armature shaft, then placed with the shaft on the lathe and turned down, so as to fit tightly in the metal cylinder (the commutator) when this is forced upon it. The cylinder is then turned up true, taking as light a cut as possible. The cylinder must then have inscribed upon its circumference 24 equidistant lines parallel to the shaft. A hole to take a $\frac{5}{8}$ " screw is now drilled at every alternate line, at about $\frac{1}{4}$ " from the one end of the cylinder, so as to have 12 holes, with a blank line between each one. 12 similar holes are now

drilled at the opposite end of the cylinder, and on the same lines. In the 12 holes farthest from the armature are to be screwed *flat-headed* brass screws, not exceeding $\frac{5}{8}$ " in length, so as to ensure not touching the shaft, and thereby producing a short circuit. The holes to receive these screws should be countersunk. The 12 holes at the other extremity are not to be countersunk, and should be fitted with round-headed screws. When this has been done the cylinder is divided into 12 equal sections, by cutting along the 12 blank lines with a sharp hack saw, until the metal segments are entirely separated from one another, and the saw touches the wood, (see Fig. 46). (Care must be taken that no metal particles are left in the slits, or short circuiting will surely arise.) When the commutator has been thus made, it should be keyed to the shaft, and then removed to allow the winding to proceed.

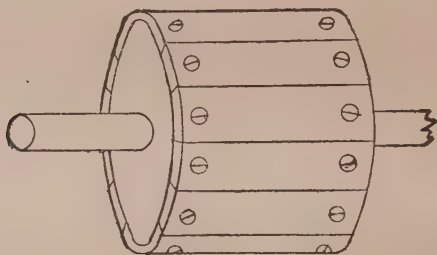


Fig. 46.

§ 46. The armature, and the shaft for a space of about an inch from each end of the armature, must now be "dressed" or "taped," as described at § 31, by wrapping round spirally with wide tape dipped in thick shellac varnish. Care must be taken to cover perfectly every metallic portion where the wire may possibly touch, to avoid electrical leakage.

Mr. Geo. M. Hopkins, in writing of winding a similar armature, says: "The winding of the armature is most readily done in a lathe. The armature shaft, with a 'dog' attached, is supported between the centres of the lathe, with 'dog' in engagement with face-plate. A spool of the wire (in our case No. 17) is supported in a convenient position at the back of the lathe, and, after bending the end of the wire around one of the wedges (at the end facing the commutator), leaving about 4" projecting beyond the wedge, the winding is begun. The wire is carried by one hand along the surface of the armature core, and

through the space between two wedges at the opposite end of the core corresponding with the space in which the coil was started. The other hand grasps the face-plate of the lathe, and as the wire is carried across the end of the armature core, the face-plate is dextrously turned through half a revolution, thus bringing the opposite side of core uppermost. The wire is then laid between the two pairs of wedges diametrically opposite those containing the wire on the other side of the armature. The wire is carried across the commutator end of the armature, at the same side of the shaft, and alongside and parallel with the wire already laid on."

Care must be taken to get the wire to lie as flat as possible at the ends of the drum near the shaft. About 8 coils will thus be got on before reaching the next wedge. The starting end of each set of coils must be coloured with some quick-drying paint or stain to distinguish it from the finishing end of coil, which must now be cut off, and twisted together temporarily, so as not to be in the way during the winding of the next coil. Calling the two channels of the armature which we have just wound by the names 1 and 1', we proceed to wind channels 2 and 2', always taking care to start at the same end, to wind in the same direction, and to pass by the shaft on the same side. When all the channels up to 6 and 6' have been wound, and each finishing end twisted to its respective beginning, it will be noticed that only 6 coils will have been laid on, and the 6 twisted ends will lie all on one side only of the armature. To get on the 12 coils it will be necessary to wind OVER the first set of 6 coils; so we bring the channel 1' uppermost, and start precisely as we did before, taking care to wind in the same direction, but now causing the coils to pass to the other side of the shaft. That is to say, suppose we caused the first 6 coils to pass always to that part of the shaft which faced us as we laid the coil on, we will now, while winding in the same direction, cause it to pass the shaft on the side farthest from us. The object of this is to cause the wire to lie compactly and closely, so as to have as little inactive wire as possible at the ends. Before laying on these last 6 coils, which overlay the others, it will be advisable to bind round the circumference of the coils laid on with strong thread, in two or three places, to prevent the coils rising from centrifugal tendency, when the armature comes to be rotated. This should also be done to the last 6 coils.

§ 47. We have now an armature wound in 12 sections, each section having its beginning and ending twisted together. We now proceed to

replace the commutator, and having keyed it to the shaft, with the round-headed screws facing the armature at that end where the twisted ends of wire protrude, we loosen these round-headed screws. Beginning at the twisted ends of our wound section No. 1 on armature, we untwist these, remove the covering from the finishing end of this coil, and likewise from the beginning of No. 2, then twist the end of No. 1 tightly together with the beginning of No. 2. In like manner the end of No. 2 coil is, after being uncovered and cleaned, joined to the beginning of No. 3, and so on all round the armature, until the end of No. 12 coil is joined up to the beginning of No. 1 coil, leaving the twisted ends protruding towards the commutator. The twisted wires, to ensure perfect electrical contact, may be run over with a soldering iron and a bit of solder. Each twist is then brought down to the round-headed screw opposite to it on the commutator, a portion of its wire looped round the shoulder of the screw, and finally the screw tightened down upon it, to make good contact between it and the commutator section below.

The details given for paraffining the wire (at § 33) may be carried out in this case, or the armature may receive one or two coats of thin shellac varnish after being wound.

§ 47a. There is another mode of winding a drum armature, which gives even neater results than the one above described, and which, if

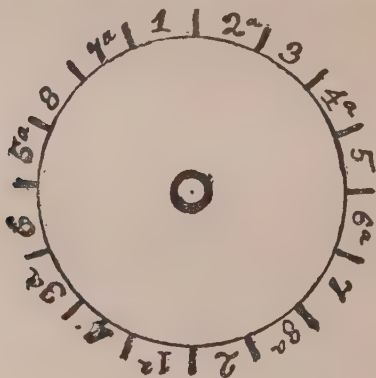


Fig. 46a.

ordinary care be taken in marking the beginning and finishing ends of each coil as laid on, presents no more difficulty to the enthusiastic

amateur than the one above described. The *modus operandi*, in the case of an armature having an eight part commutator, is as follows: Having built up the drum of punchings or washers, a washer with 16 projecting teeth or lugs must be placed at each end, and the whole bolted on to the spindle. The drum must be dressed carefully with paraffined silk, tape, or other insulator. The appearance of armature should be as shown at Fig. 46a. The numerals which indicate the corresponding coil-spaces top and bottom, &c., should be noted.

Now, having supported the armature between the centres of a lathe, or similar centres, the operator proceeds to wind coil, 1 and 1a, beginning against the left-hand tooth above, and ending against the right-hand tooth below. In order to be able to recognise the beginning and finishing ends of each coil, for after connection, the starting end should be bound with a bit of bright-coloured silk, leaving the termination end unmarked. The operator now draws the termination end up to the starting end, twists them together, and cuts them off, leaving sufficient length for joining up to commutator. The armature now presents the appearance shown at Fig. 46b. The operator now turns

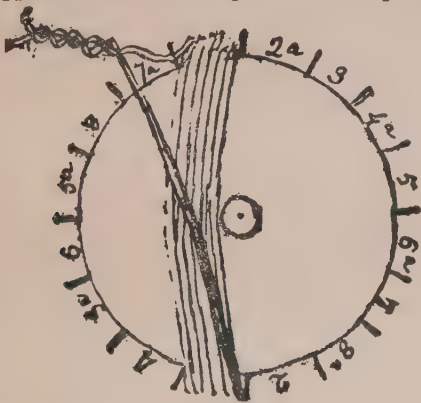


Fig. 46b.

the armature round half a revolution, so as to bring coil space 2 uppermost, and he winds this coil 2 precisely as he did coil 1, starting against the left-hand tooth above and ending at the right-hand tooth below. This must be marked in the same manner as before, the starting end with a bit of bright-coloured silk, and, as before, the terminator drawn up to the starter, and the two twisted together and

cut off. If this has been correctly done the armature should appear as Fig. 46c.



Fig. 46c.

The operator proceeds now to wind, in a precisely similar manner,

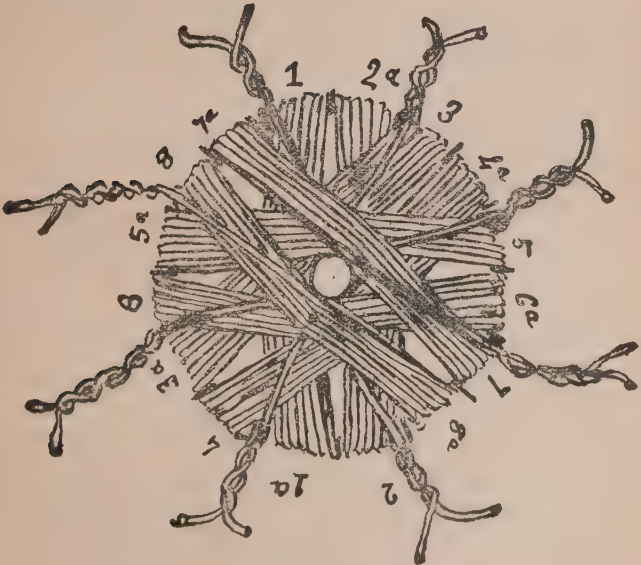


Fig 46d

coil 3, and when this is done, turns the armature over so as to bring coil space 4 uppermost, which he will wind and cut off in like manner. By thus turning the armature through half a revolution, after winding each coil on, although he always starts against the left-hand tooth above, and always winds to the left of the spindle, he will find that the coils will lie alternately to the left and right of the spindle. He must go entirely round the armature as described above. When this has been done, the armature will appear as shown at Fig. 46*d*. He now goes round the armature, untwists the wires of section 1, and joins the terminating wire of section 1 to the beginning wire of No. 3, the ending wire of No. 3 to the beginning wire of No. 5, the ending wire of No. 5 to the starting wire of No. 7, the termination of No. 7 to the commencement of No. 2, the end of No. 2 to the beginning of No. 4, the termination of No. 4 to the starting wire of No. 6, the end of No. 6 to the commencement of No. 8, and lastly, the end of No. 8 to the to the starting wire of No. 1. This completes the circle of connections. He must now solder each pair of wires to its respective commutator section, as described at § 47.

§ 48. The field magnets may take any desired form, provided that the cores will hold the requisite amount of wire, and the tunnel be large enough to admit the armature. The calculation as to the amount of wire required to balance that on the armature will be gone through here, as it will exemplify the mode of working out similar questions. The 90 yards of wire used on the armature will weigh very nearly 3 lbs. As each lb. of No. 17 has a resistance of nearly 0·3 of an ohm, the total resistance of this length of wire is 0·9 ohm. But the actual resistance of the armature when running between the brushes is, as we have already seen (§ 43), only $\frac{1}{4}$ that of the total length of wire, therefore we reckon the armature resistance as 0·225 of an ohm. If we desire to balance this with wire as a series machine, using wire of four sizes larger, we find that No. 13 has a resistance of about 0·04 per lb. About 6 lbs. of this wire will be required to give the $\frac{2}{3}$ needed to balance the resistance of armature wire (see § 41); and as this wire runs about 11 yards to the lb. and 11 coils to the inch, it is evident that this amount of wire could be easily laid on two field-magnet cores, $6\frac{1}{2}$ " high, $5\frac{3}{8}$ " wide, and $1\frac{1}{8}$ " thick, putting about four layers on each limb or core. (It is never advisable to use wire of such a diameter as to cause the coils to be greater in thickness than the iron of the cores, as, if this be done, the magnetis-

ing effect of the outer coils is to a great extent lost.) As the tunnel in which the armature is to turn must be about $3\frac{5}{8}$ " in inside diameter and $6\frac{3}{4}$ " in length, this gives us for the total dimensions of the field magnets, with pole pieces and yoke, 13" high; the pole pieces being $6\frac{3}{4}$ " long, 4" high, and $4\frac{1}{2}$ " wide.

If the machine is to be *shunt* wound, we must choose the largest wire giving the desired resistance that will lie in the above-mentioned spaces. Bearing in mind that this being a rather small machine, we cannot greatly exceed 100 times the armature resistance, viz.: $= 100 \times 0.225 = 22.5$ ohms. We find on reference to a wire table that from 8 to 10 lbs. No. 20 will give the required resistance without overshooting the allotted space, since No. 20 lies 23 coils to the inch, and runs 80 yards to the lb.

§ 49. Except that the bearings, being much larger and requiring to be much stronger, must be solid brass castings, to be properly fitted to the carcase by screws, there is no great difference in design between this and the smaller machine previously described. But in these larger machines it is advisable to have adjustable brushes, supported by a movable "rocker," furnished with a "set screw," so that the brush can be adjusted to the angle which gives the best result in picking up the current, and, at the same time, the least *sparking*, which always points to waste of power. Fig. 47 shows the shape to be given to these

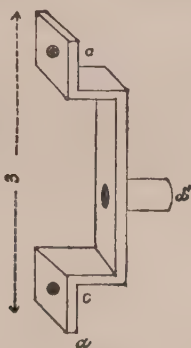


Fig. 47.

heavier bearings; and Fig. 48 illustrates a form of rocker which it will be convenient to adopt, to enable the rocker to slip over the nose of the front bearing.

In connecting this (or any other) dynamo in *shunt*, the student will remember that the field-magnet wires, which are left free after having

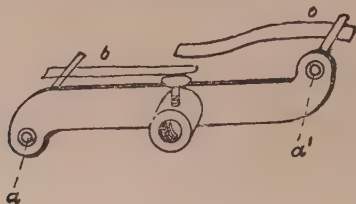


Fig. 48.

connected up the inner wires (see § 38, Fig. 33), are to be coupled up, one to each of the brushes; and that *if by a mistake in winding* it be found that the machine requires to be driven against the brushes to make it give current, this defect can be remedied *by reversing the relative coupling of these wires to the brushes*. For example, let us suppose that when the wire from the *right-hand* field-magnet limb is connected to the right-hand brush (the left-hand wire being connected to the left-hand brush), that the machine requires to be driven *against* the brushes; then by crossing the wires, so as to cause the left-hand to couple up with the right-hand brush, and *vice versa*, the dynamo will be found to give current when driven normally, that is to say, with the brushes. From the brushes, two stout cables made of 3 or 4 strands of No. 22 wire, gutta-percha or indiarubber covered, are carried, one on each side, to the terminals. Fig. 49 shows the general arrangement of a large drum armature machine, similar to the one described, the chief differences being that the field-magnet cores are circular in section (and this is the best form when it is possible to adopt it), and the rocker (with the brushes) is inside the bearings instead of being outside.

§ 50. It will be quite obvious to the intelligent reader that the above described drum armature (which is known as the Siemens' Alteneck, or Hefner-Alteneck armature) could be made to work in field magnets of any pattern, such as the originally devised horizontal form (Fig. 50), the "A" Gramme form (Fig. 51), or the "Manchester" pattern (Fig. 52). The only point that calls for notice here is that, with field-magnet carcasses of these shapes, in which each pole piece is connected to *two* cores, it is necessary *to reverse the direction of winding* on crossing over from one field-magnet core to the other on the opposite

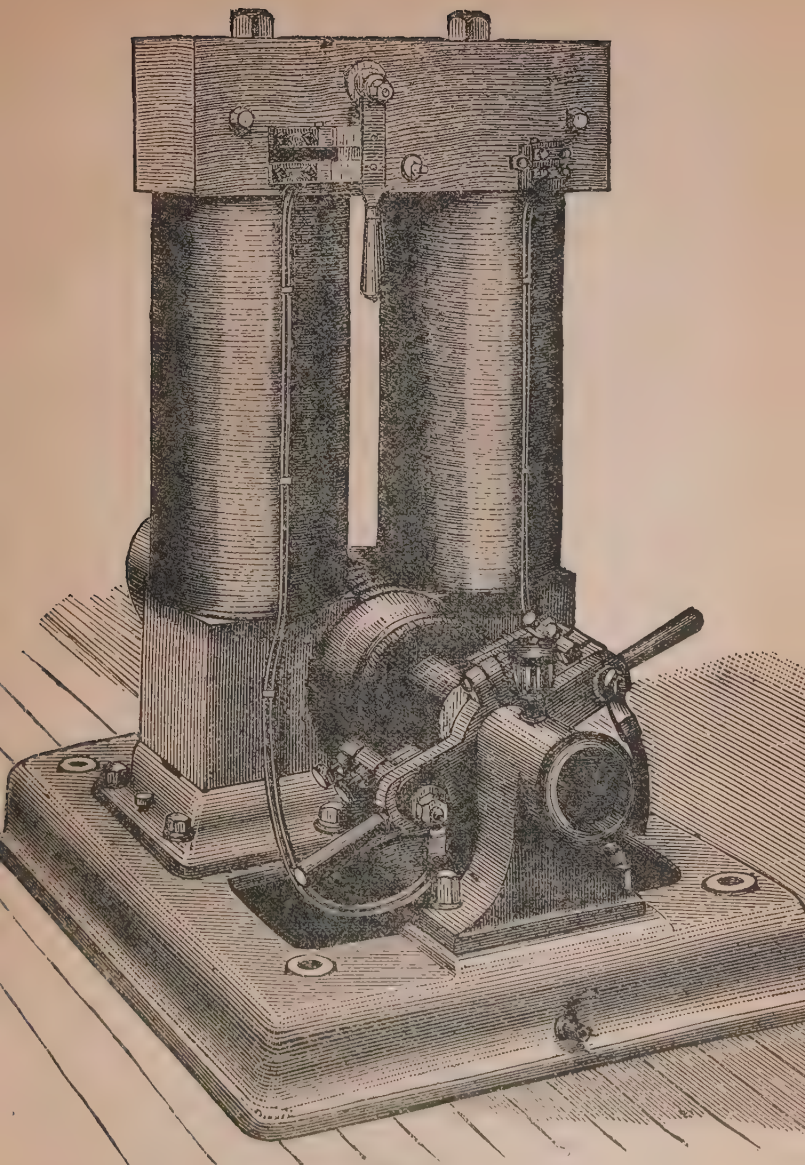


FIG. 49.

side of the pole piece, otherwise the pole pieces, instead of acquiring a definite polarity, would be neutral, and the dynamo would not work.



Fig. 50.

The mode of coiling the wire so as to secure "consecutive" poles at the pole pieces, these poles being respectively N above and S below, is well illustrated by the dotted lines in Fig. 51.

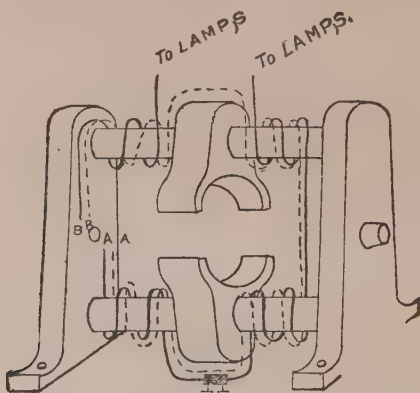


Fig. 51.

§ 51. RING ARMATURE DYNAMO. Ring armatures, such as depicted at Figs. 13, 44, and 45, may be made to work in field magnets of any of the above-mentioned patterns. The annexed Figs. 53, 54, and 55 will serve to illustrate modifications in design given to field magnets for ring

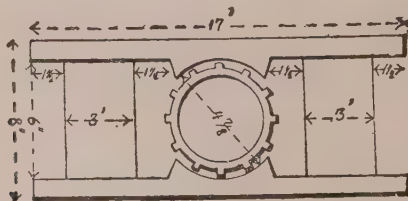


Fig. 52.

armatures. For constructing dynamos with armatures of this type, the "Gramme" (Fig. 51), and the "Manchester" (Fig. 52), will be found the

most generally useful forms to adopt. The "Simplex" (Fig. 54), the "Alliance" (Fig. 55), and its congener (Fig. 53), are perhaps somewhat

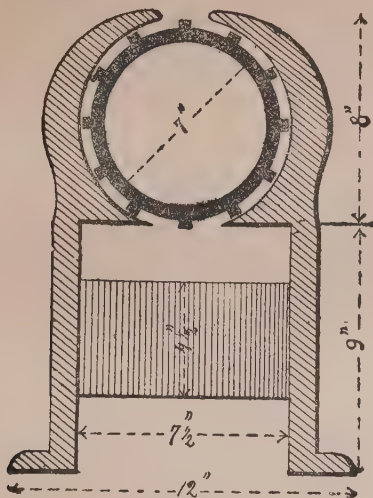


Fig. 53.

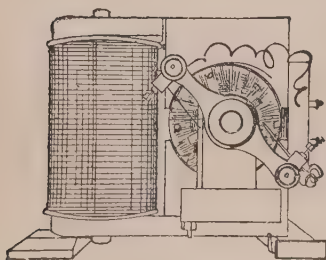


Fig. 54.

more efficient electrically ; but this latter has a great disadvantage, that the centre of gravity of the rotating armature is necessarily very high ; hence there is a good deal of unpleasant and injurious vibration. To make, say, a "Manchester" type of machine, to light 10 lamps of 16 c.p. and 50 volts, we should need a ring armature 6" diameter, about 6" deep. This may be either a cast ring, with twelve cogs, as shown at Fig. 56, or, better

still, built up of a number of punchings or "laminations" of the same shape, stamped out of good charcoal sheet iron, about $\frac{1}{16}$ " thick, with

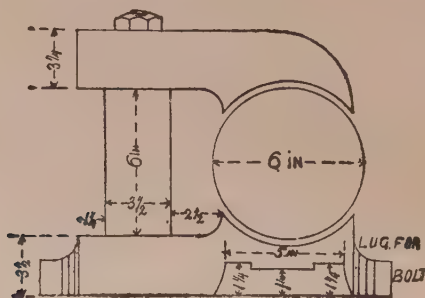


Fig. 55.

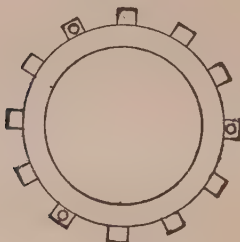


Fig. 56.

holes punched through every third or fourth tooth to allow them to be strung on rods through these holes, and bolted to spiders in gun metal, with three or four arms of the pattern shown at Fig. 57, by means of

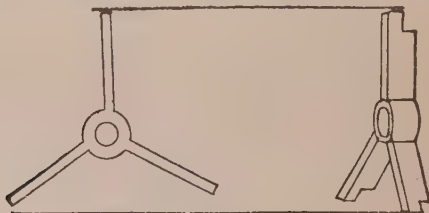


Fig. 57.

nuts at each end. When the armature has been fitted to the spiders, these latter can be temporarily removed, and the rings clamped together

by means of the nuts, for the convenience of taping (§§ 31 and 46) and winding the armature. It will be well to place little wooden blocks, a trifle larger than the arms of the spiders, just under those nuts where the spiders will eventually be fitted, to prevent the operator incautiously winding the wire *over* these places. These blocks or ferules should of course have holes through them to admit the passage of the screwed rods, on to which the nuts screw down. The greatest care must be taken in "dressing" the ring, inside and out, for if any bare iron be left, it will be almost certain to cut through the insulation of the wire during winding. To this end a piece of thin silk is cut, a little wider than the ring, and of sufficient length to line the inside. This is attached to the inside by means of a little good hot glue. In like manner a strip is cut off, of such a length that it will go all round the outside of the ring, and in between the cogs. This piece is also glued on, special care being taken to make it fit squarely in the channels between the cogs. Lastly, the front and back edges of the ring are carefully covered over with quadrantal pieces of silk. When quite dry, this dressing should receive a good coat of thick shellac or white hard varnish. (The silk at the top of the cogs need not be varnished, as it will be cut away when the armature is wound.) The armature is now clamped by its edges at a convenient working height, say, about 36" from floor level, to a firm bench, by means of a vice or clamp. A shuttle of the general form shown in Fig. 58 is now



Fig. 58.

cut out of a piece of any hard wood (a piece of cigar-box lid will do very well for this particular armature), the width of which must not exceed one half the inside diameter of the ring. On this shuttle must be wound sufficient wire to fill one channel of the armature. Since the entire armature of this size will take somewhat less than 5 lbs. of wire, each of the twelve channels will take about 6 oz. of wire. It will be well to weigh the armature before winding one channel, then weigh again when one channel has been wound in, and then to cut off eleven similar lengths of the same wire, so as to insure that each channel or "section" has the same amount of wire upon it. The wire used on this armature should be No. 16, d.c.c., to enable us to get sufficient E.M.F. and carrying capacity. It is much easier for two persons to wind the armature

than for one alone to do it, and in the following directions I shall suppose two persons to be at work upon it. The one who has the most skill I shall term the *operator*, the other the *assistant*. Standing at that side of the armature which when fitted is the nearer to the commutator, the operator bends about 2" of the wire round to the left of the top cog, and then lays the wire tightly and flatly along the right hand of that same cog, as shown at Fig. 59. The assistant then takes the shuttle and

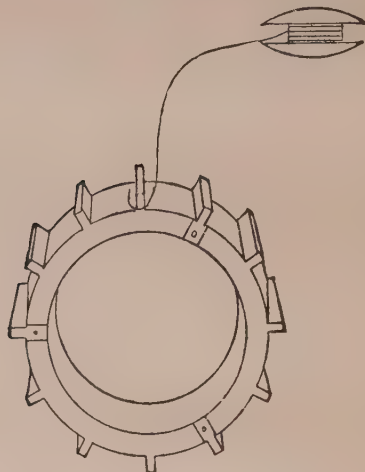


Fig. 59.

passes it inside the ring to the operator, who draws it through, and lays a strand straightly and tightly along the inside of the ring, pulling pretty hard to insure the wire lying flat and tight. He then passes the shuttle to the assistant, who again pulls towards himself, in so doing laying another strand of wire over the ring, close against the one previously laid on. If there is any unevenness, or space between the wires, a smooth wooden or bone paper-knife may be used to press the wire flat into its place. The assistant again passes the shuttle inside the ring to the operator, who, in his turn, lays another strand inside, close against the first one, and again passes the shuttle to the assistant, and so on until the next cog is reached. Continuing in the same manner, and winding over the layer just laid on, coming back towards the cog from which the commencement was made, a second layer is put on, and so on

until all the wire on the shuttle is wound on, and the channel filled. In order that the wire may not uncoil, it will be well to turn the bent end of the starting wire straight, and twist it pretty tightly to the finishing end. This finishing end should, in view of avoiding mistakes in after-operations, be marked in some distinctive manner—say, by colouring an inch or two of its length with red Aspinall's enamel, or other quickly-drying colour. Before proceeding to lay the wire in the other sections, it will be advisable now to test whether the insulation of the coils just laid on is perfect. As this is of the highest importance, and *must* be done to each section as each section is in its turn laid on, the modes of testing are here described.

§ 52. The first and simplest, if a pretty strong battery or other source of current electricity be at hand, is to connect one pole of the battery with the finishing extremity of the wire laid on (which must, of course, be bared of its covering at this point to insure good electrical contact), and then draw the other pole of the battery along some bared portion of the ironwork of the armature. As it has been recommended to cover the armature *entirely* with silk, the available points of contact in the present case will be the heads of the screws, which hold on the wooden blocks that hold the places of the arms of the spiders. On touching the iron with the free pole of the battery, if the insulation is perfect, *not the slightest spark should appear*. If any spark is seen on drawing the wire along the iron, it shows that the current is leaking through to the iron, and the insulation is defective. The second method, which is much more delicate, necessitates the employment of a galvanometer. As before, one pole of the battery is connected with one of the ends of the wire just laid on, the other pole is then connected to one terminal of the galvanometer. A piece of wire is now connected to the other terminal of the galvanometer, and the free end of this latter wire is made to touch the bare iron or screw of the armature. *No deflection should take place*. If under these tests it should appear that the insulation is defective, the section must be unwound, the bare place in the iron again carefully dressed, and, when rewound, again tested until perfect insulation has been attained. In precisely similar mode in which the first section has been wound, the remaining channels are to be filled in.

§ 53. Another mode of winding specially adapted to larger motors and dynamos is the one recommended by Mr. F. W. Walker, in his excellent little work, *Practical Dynamo Building for Amateurs*, which originally appeared in the pages of the *English Mechanic*, and which I

reproduce here, with trifling modifications, to fit it for the cog or Pacinotti form of armature. Having described the shuttle for the wire, Mr. Walker proceeds to say: "Two shuttles of hard wood, nicely rounded, a mallet, and a hard wood wedge, with rounded and smooth edges and surface, now complete the winder's outfit. Upon one shuttle should be wound, with a little to spare, the length of double cotton-covered wire that has previously been calculated for one coil; then, if the winding is to be four layers deep, four full perimeters of wire should be wound off upon the second shuttle. In describing this operation, in order to render the use of the two shuttles more clear to the amateur, the first, holding the bulk of the wire, will be termed No. 1, and the other, with four layers upon it, No. 2. Beginning close to the cog to his right, the winder passes No. 2 through the armature to his assistant, who thereupon hangs a weight to it, and then he receives No. 1 from the winder over the top of the armature, passes it back to him through the interior, receives it again, and so on, straining tight each time, and bringing the strands level with the mallet and wooden wedge. A short piece of tape is laid upon each edge of the core, so that the last two turns pass over it, leaving an end of tape free when the other cog is reached. The last turn being laid close to the cog, the tape end is brought up between the wire and cog, then the first turn of the second layers is made by the assistant over the top with No. 1 shuttle, No. 2 remaining neutral all this time. The second turn of this layer should bind the tape end over the first, thus securing it from slipping. Then a weight should be attached to No. 1 by the winder while he gives the layer a good coat of shellac varnish. The tape ends should again be laid ready to bind in the last turn, and the winding proceed until one turn is required to bring the second layer close to the starting cog. Instead of performing this turn with No. 1, the winder hangs a weight to it when he receives it from his assistant at the finish of the last turn but one, and this final turn completed with No. 2 shuttle, which the winder passes back, and again receives from the assistant over the top, and returns through the armature, so that No. 2 makes the last turn of second layer, and first turn of third; then is weighted by the assistant, and again remains neutral for a time. The third layer now proceeds with No. 1 to the other cog, the last turn being taped as before, and the first turn of the fourth and last layer is begun with No. 1 shuttle, and wound until the last turn but one, when the assistant passes it through to the winder, when it should be nearly empty. No. 1 shuttle is then passed over and completes the last turn, and with the end of wire from No. 1, and

the end from No. 2 respectively, coming through and over, the winder pulls taut, and makes a neat and tight twist with the pliers, taking care to place some tape between the wires in case of a short circuit. By this arrangement of two shuttles, the final ends are brought out in the last layer, over and under, and the distortion and risk of short circuit consequent upon leaving the first end to protrude through the whole winding prevented."

§ 54. Whichever plan of winding has been adopted, the armature will now be ready for being properly coupled up. For this purpose the operator will begin by untwisting the ends of one of the sections, and having bared the *finishing* end of this said section, and sand-papered it to get a good clean surface, will cause his assistant in like manner to untwist the wires on the next section, and bare and clean the *beginning* extremity of this next section. He will then twist up together pretty tightly, and afterwards solder the *end* of the first section to the *beginning* of the next, and so on until all the sections are thus joined, using two precautions: (1) To place a piece of tape or paraffined paper under the wires previous to twisting up, to prevent any chance of short circuiting with the layers of wire beneath; (2) To leave about 4" of free ends of

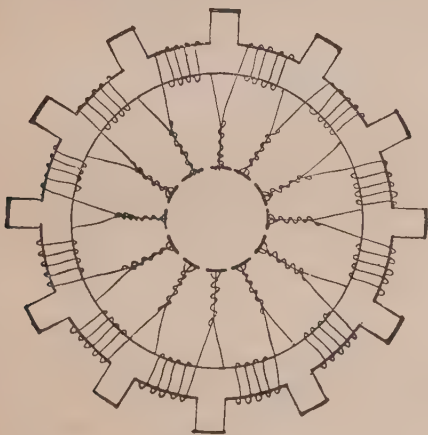


Fig. 60.

wire for after attachment to the commutator. When the sections have been all thus properly connected, as shown at Fig. 60, the layers of wire

should receive a coating of some insulating material. Some operators employ thin shellac varnish, others place the armature in a gentle oven, and place over it lumps of paraffin wax, and allow the heat of the oven to melt the paraffin until the layers of wire are permeated with it. For small armatures I prefer the latter plan; for large ones, the former. When the operation of varnishing or paraffining has been completed, the armature may be mounted on the spindle (the wooden blocks having been previously removed to allow the arms of the spiders to fit in their places), and the twisted ends of the wires fastened down, each one to its own segment of the commutator, by means of the round-headed screws, as shown at Fig. 60.

§ 55. The operator, having decided upon which pattern of field magnets he intends to adopt, will proceed to "dress" or "tape" them as previously described to insure insulation, and then wind the cores, if intended for a "shunt" machine, with about 40 lbs. No. 20 d.c.c. copper wire, which will give nearly 400 times the resistance of the armature coils. Should he, on the contrary, desire to use the dynamo for arc lighting, he will do better to wind the field magnets for "series," in which case, if he puts on 40 lbs. of No. 12, in two strands, and then connects these two strands up in parallel (to reduce the resistance to $\frac{1}{4}$), he will get good results. All the other details as to connection with brushes if shunt wound, or to one brush and one terminal if series wound, will be precisely the same as in the machines previously described, the only precaution to be borne in mind being, that in the case of a form of carcass being employed, in which the pole pieces come between *two* magnet cores (as in the "Gramme" or "Manchester" types), the wire, in passing from the one core to the other, must reverse direction of winding, to ensure the necessary consecutive poles.

ON FAILURES IN DYNAMOS, AND THEIR CAUSES.

§ 56. The intelligent amateur, who has carefully followed out the directions given in the foregoing pages, can hardly have failed in building a dynamo, working well, and giving satisfaction. Unfortunately, even in dynamo making, the old Latin proverb, "Humanum est errare," holds good. In the hopes of meeting the requirements of those amateurs who have been unsuccessful in getting their dynamos to work, the author has penned the following instructions, which will enable any one gifted with a little patience, not only to localise the fault, but to remedy it with ease. In order to be clearly understood, some of the matter appearing in the foregoing pages will be recapitulated here: this is almost absolutely necessary, because most of the defects and failures depend on want of attention to little details; and by reiteration, and reiteration only, can these be impressed on the memory.

§ 57. *Apparatus Necessary.*—In order to localise the defects of a dynamo, the following appliances are absolutely necessary: (a) a

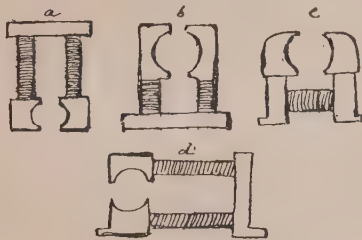


Fig. 61.

Dynamo Carcasses of the First Type: (A) Pole-pieces, downwards; (B) Over-type; (C) Yoke, wound; (D) Horizontal. In all these the lines show where the wire is coiled.

poised magnetic needle; (b) a fairly sensitive galvanometer; (c) a battery of at least six cells of the bichromate or chromic-acid type; (d) a cheap Wheatstone's bridge; (e) a few lengths of German silver wire. Directions for making all these appliances at a very moderate cost will be found in the author's book, *Electrical Instrument Making for Amateurs*.

§ 58. We may divide the carcasses of dynamos, for the purpose of diagnosis, into the following three types: (1) Fig. 61, those with a single pair of field magnets, in which the two pole-pieces are at the

extremities of the field-magnet cores farthest from the yoke ; (2) Fig. 62, *a* and *b*, in which there are two or more field-magnet cores, con-

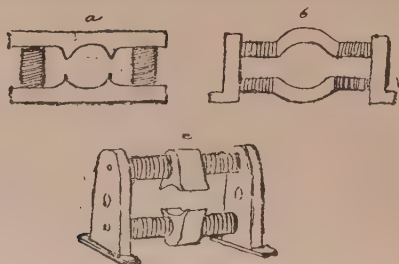


Fig. 62.

Dynamo Carcases of the Second and Third Types : (A) the Manchester ; (B) the Horizontal Siemens ; (C) the Gramme.

nected at the top and bottom by yokes which carry the pole-pieces, and which must therefore be wound so as to produce consecutive poles in the centre of the said pole-pieces of opposite polarity ; (3) Fig. 62, *c*, those of the old A Gramme type, in which there are four field-magnet cores, the two upper having a pole-piece between them, and the two lower furnished likewise with a similar pole-piece. These, like the ones belonging to class 2, must be wound so as to produce consecutive poles above and below of opposite polarity.

§ 59. Armatures may for our purpose be conveniently divided into four classes, *viz.* : (a) Fig. 63, the Siemens H, also called the Shuttle or the

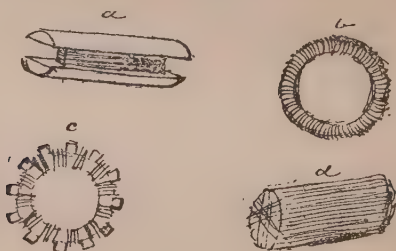


Fig. 63.

The Four Chief Types of Armatures : (A) the Shuttle, or old Siemens ; (B) the Gramme Ring ; (C) the Pacinotti ; (D) the Drum. The lines indicate the portions to be wound with wire.

Girder, armature. This is the amateur's favourite model, as it is easy to make, easy to wind, and for small machines gives excellent results ; (b) Fig. 63, the Gramme armature, consisting either of a solid ring of iron or else of a ring built up of iron wire or laminations ; (c) Fig. 63,

the Pacinotti armature, very similar to the latter, but differing in so far as the ring, whether it be of solid iron or built up of laminations, has teeth projecting round the circumference, between which teeth the coils of wire are wound; (d) Fig. 63, the drum armature, in which the core takes the form of a long cylinder of iron, either solid, or built up of plain discs, over which the wire is wound longitudinally.

§ 60. We may divide commutators into two great classes: (a) Fig. 64, those having only two sections, and (b) Fig. 64, those having more



Fig. 64.

The Two Classes of Commutators: (A) the two-section Commutator; (B) the many-section Commutator.

than two sections. The former are used with the Siemens H armature, the latter with the other forms.

§ 61. In order to impress upon the mind of the reader the different types of machines of which it is proposed to treat, illustrations typical of the different classes of dynamos, armatures, and commutators, are subjoined, by means of which the reader can quickly ascertain to which category his dynamo belongs. It must not be inferred that these are the only forms that can be given to dynamos and their appurtenances; for their modifications are almost as numerous as are the men who have interested themselves in their improvement. The types given, however, are those to which the amateur generally directs his attention.

§ 62. Although it is usual to speak of the modes of winding the dynamo as being divisible into three classes, yet, as a matter of fact, the actual winding is the same in all three cases, the difference really lying in the manner in which the wire, or wires, used for winding the dynamo, are connected to the brushes and to the outer circuit; hence we abusively term a machine in which one end of the field magnet coils is attached directly to one brush, the other end of the F.M. coils being led direct to the outer circuit, and thence making connection to the outer brush, a *series-wound* machine from the fact that the entire current is generated by the armature, passes in series along the F.M. coils and the outer circuit in its way back again to the armature. As a natural result of this mode of winding, since the magnetism of the field-magnets depends on the amount of current that passes around their coils, the *resistance* which it is possible to put in the outer circuit (in the shape of lamps or other work to be done) is limited, inasmuch as any great resistance would so far cut down the current as to render the dynamo inoperative, owing to the F.M.'s being insufficiently magnetised. In a so-called *shunt-wound* machine the two extremities

of the F.M. wires are connected directly to the brushes, the brushes themselves being connected with the outer circuit. As a consequence of this the current generated by the armature finds two paths open to it: firstly, from brush to brush around the F.M.'s through the coils, and, secondly, from brush to brush along the line of the outer circuit (be it lamps, motors, etc.). In obedience to the law that regulates the flow of currents along divided circuits, the current will divide itself among these two paths in proportion to their relative conductivity; and if, as should always be the case in a shunt-wound machine, the resistance of the F.M. coils be considerably higher than that of the outer circuit, a proportionately larger amount of current will be available for work in the outer circuit. In order that sufficient magnetism shall be imparted to the F.M.'s by the smaller current passing along their coils, advantage is taken of the fact that the same magnetising effect is produced by causing a current, say of one ampère, to circulate 100 times round an iron core, as that which is produced by a current of 100 ampères circulating once round the same core. Or, to state the fact in other words, one turn of wire carrying 100 ampères produces precisely the same magnetising effect as 100 turns of wire carrying but one ampère. So by winding a large number of turns of fine wire round the F.M.'s two ends are served: in the first place, the F.M.'s are sufficiently magnetised with a small current; and, in the second place, the dynamo becomes to a certain extent self-regulating, since on increasing the resistance of the outer circuit, more current is *shunted* round the F.M. coils, thereby increasing the power of the F.M.'s, which, in its turn, enables the armature to generate a current of higher E.M.F., and thus overcome the increased resistance. It must be noted, however, in this connection, that a shunt-wound dynamo will fail to work under conditions precisely the opposite to those which nullify the performance of the series machine. For, if the resistance of the outer circuit fall below a certain point, then such a large portion of the entire current generated by the armature flows into the outer circuit, and so little passes round the F.M.'s, that these latter do not become magnetised, and the armature ceases to produce current. In the so-called *compound-wound* dynamo two distinct sets of coils are wound around the F.M.'s, both in the same direction. One set is of coarse wire, which is connected to one brush and one terminal, precisely as in the series machine; and the other set consisting of many turns of finer wire is connected directly to the brushes as in the shunt machine, and this latter is not connected to the outer circuit at all. As a result of this mode of arrangement a well-made compound-wound dynamo is almost perfectly self-regulating, inasmuch as if the resistance of the outer circuit be very low, then almost the whole of the current generated in the armature traverses the series coils and the outer circuit; while, on the contrary, if the resistance of the outer circuit be made very great, the shunt coils come into play, and allow the passage of sufficient current to keep up the magnetisation of the F.M.'s to a point sufficient to raise the E.M.F. to the degree necessary to overcome the increased resistance in the outer circuit.

§ 63. Having cleared the ground of these few technicalities, we can

at once begin the examination of our defective dynamo. The first step is to ascertain whether the insulation is good. To this end we can begin testing it as a whole, *i.e.*, without removing the armature. For this purpose we couple one of the terminals of the dynamo to one of the terminals of our galvanometer, and, having attached one pole of our six-cell bichromate or chromic-acid battery to the other terminal of the galvanometer, we proceed to touch any of the bare iron portions (such as are bright and clean) of the dynamo carcase with the wire proceeding from the other pole of the battery. The armature spindle or the bolts passing through the yoke of the dynamo are generally clean, and therefore available for this purpose. If on touching the bare iron with the battery wire the galvanometer needle gives a deflection, our dynamo leaks, or, in other words, the insulation is defective at some point.

§ 64. Fig. 65 shows the mode of connecting-up battery to galvanometer and dynamo in order to perform this test. Here D represents the dynamo, B the battery, WW the wire leading from battery through galvanometer to one terminal of the dynamo; W represents the other

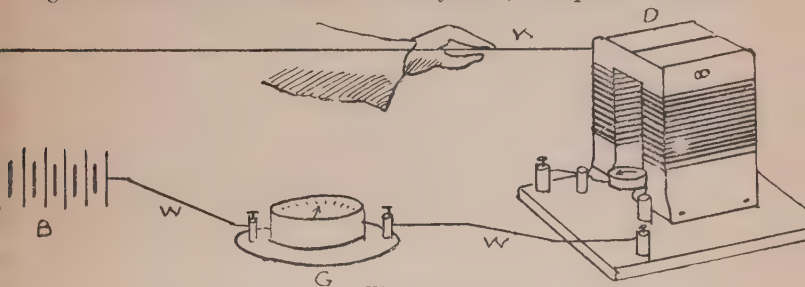


Fig. 65.

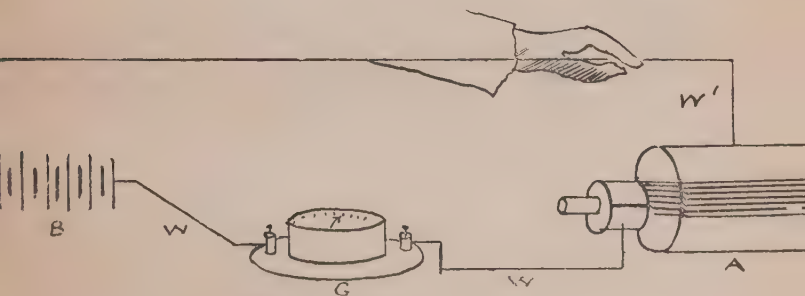


Fig. 66.

wire with which the bare iron of the dynamo is touched in order to see if any leakage exists. We will suppose that the galvanometer deflects, thus proving the presence of a leak. Our next step will be to ascertain where this leak occurs. It may be in either of the following places: (1) between the F.M. coils and the F.M. cores themselves, (2) between

the armature coils and the armature core itself, (3) between the outer coils of the armature and the bearings between which the armature plays, (4) between one or both of the brushes or brush pillars and the brasswork of the bearings.

§ 65. Beginning by the brushes, we notice whether these, while pressing as they ought to do on the commutator, are by any chance touching at the same time any part of the iron or brass frame of the dynamo, or whether, in the case that the brushes are attached to a "rocker," there is any short circuit between the two brushes. This point having been ascertained, and the defect remedied if such exist, the dynamo is once again tested for insulation, as before. Again let us suppose that the galvanometer deflects, proving that a leakage still exists, we proceed to test the insulation of the F.M. coils as follows.

§ 66. To ascertain whether the insulation between the F.M. coils and the cores is defective, we remove the brushes entirely, and having connected one end of the F.M. wires to battery and galvanometer, as shown at Fig. 65, we proceed to touch the bare iron, as before, with the other battery wire. If the galvanometer needle remains stationary, the insulation is good; if the needle is deflected, the F.M.'s are leaking, and will probably require re-winding. It often happens, however, that the leakage may be taking place at the top or bottom end of the coils where they touch the bent portion or portions of the iron core, and in this case it is sometimes possible, by inserting a thin, wedge-shaped piece of vulcanised fibre between the coils and the iron, to remove the coils from actual contact with the iron, which will, of course, prevent leakage, the piece of fibre being afterwards fastened in its place by pouring in a few drops of hot, melted paraffin wax. It may happen, however, that the F.M.'s do not leak, in which case we proceed as in the next section.

§ 67. To test for leakage in the armature, the brushes being, as before, removed, we connect the battery and the galvanometer, as shown at Fig. 66, and place the galvanometer wire firmly in contact with one section of the commutator, and then touch any of the bare iron portion of the armature with the other wire proceeding from the battery. If the needle of the galvanometer is deflected, leakage is taking place between the armature coils and the armature core. For the sake of example, let us take it that no deflection occurs, in which case the armature coils may be rubbing against the back bearing.

§ 68. To ascertain whether there be any leakage between the outer armature coils and the back bearing (due to an insufficient length of shoulder having been left on the armature spindle, or to the wire having been wound on beyond the shoulder), it will be generally sufficient to examine carefully the back end of the armature, after having removed the bearing, to see whether the covering of the wire has become abraded by friction against the bearing. (By "back end" of armature and "back bearing" are understood those portions which are farthest from the commutator end, which will hereinafter be termed "front end" and "front bearing" respectively.) It may happen that owing to an insufficient shoulder being left to the spindle at the front end, the com-

mutator may touch the front bearing; in which case, leakage would take place between the points which touch. To ascertain whether this is the case, a thin washer of brown paper may be placed between the commutator and the front bearing, when a repetition of the battery test will speedily indicate, by the quiescence of the needle of the galvanometer, that the leakage was occurring at that place.

§ 69. Having localised and remedied the leakages, if any, we proceed to put our dynamo together and test it again. Still it gives no current! We now must ascertain the condition of its polarity, that is to say, whether the pole-pieces have or have not a proper N. and S. polarity. (It is supposed that the student has already imparted magnetism to the F.M.'s by coupling-up the two ends of their wires to a battery of sufficient strength.) On approaching the pole-pieces with an ordinary pocket compass or any other delicately poised magnetic needle, the one pole-piece should strongly attract one end of the compass needle, while the other pole-piece should as distinctly and strongly attract the other end of the compass needle. Should by any chance both pole-pieces give indications of similar polarity, by both attracting or both repelling the same end of the compass needle, or should any other portion of the F.M.'s evince stronger polarity than the pole-pieces themselves, then the F.M. wires are wrongly connected, or else the pole-pieces themselves are resting on, or near to, an iron base, which consequently neutralises their polarity. As the proper connection of the F.M. wires to each other varies with the type of machine, we will make the careful consideration of the correct mode of winding, and afterwards of connecting-up the F.M.'s, the subject of our next paragraph.

§ 70. On reference to § 58, it will be noticed that we divided the field-magnets of dynamos (for our special purpose of ascertaining defects) into three great classes. In order to facilitate the comprehension of the manner in which the mode of winding is influenced by the pattern of the F.M. used, we will study the effect produced by winding wire carrying a current in a given direction round a straight cylindrical bar, such as illustrated at Fig. 67, in which the wire is wound from left over to right under, beginning at the left hand of the bar. If the current enter in the direction of the arrow, a north pole will be produced at N., and a south pole at S. If, while the wire is on this, we could bend the bar into the shape of a horseshoe, and somewhat compress the coils, so

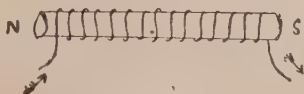


Fig. 67.

as to clear the bent portion, as shown at Fig. 68, we should find that the wire would *apparently* be coiled in the opposite direction in the one limb to that on the other, or, to speak more correctly, that the wire leaving the left-hand portion of the bar from behind would start its convolutions in front of the right-hand bar. It will be perfectly evident that the polarity set up in the magnet after the bar is bent will be

precisely the same in this case as in the former, since the wire is really continuously wound in the same direction. Whether the bare part at

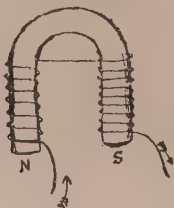


Fig. 68.

the belt consist of a portion of the bar itself, as shown at Fig. 68, or whether the two wound limbs be connected together by means of a

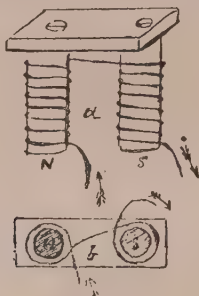


Fig. 69.

heavy iron yoke, as shown at Fig. 69 (where A is an elevation, and B a plan of such an electro-magnet), is absolutely indifferent, in so far as the polarity set up is concerned. It is therefore evident that whenever we desire to produce magnets having two poles only of opposite polarity with only two wound cores, the above mode of winding is the only one

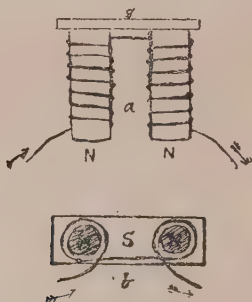


Fig. 70.

admissible, since it is the only one which can give poles of opposite polarity at the two free extremities of the cores. Such magnets are generally termed single magnets. The beginner is very apt to start winding from the inside or from the outside of both cores; and the result of this is, that when he joins them up he gets a winding in the opposite direction on the two limbs, as shown in Fig. 70, where A is an elevation and B a plan showing this erroneous mode of connecting-up; the result of this would be the production of two N. poles below and a strong S. pole at the top yoke. Even supposing this mistake to have been made, there will be no necessity of unwinding either core; as the current can be sent in the proper direction by disconnecting the wire as at J, Fig. 71, and joining the top left-hand severed portion to the bottom free end of the wire on the right-hand limb, using the right-hand severed end as the portion to be connected with the terminal. This mode of remedying a false winding by reversing the connection of

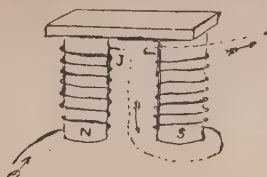


Fig. 71.

the four free ends of the F.M. wires is shown by the dotted lines at Fig. 71.

§ 71. If our bar, instead of being wound, as in Fig. 67, continuously in one direction, were wound one half with a right-handed spiral, and the other half with a left-handed spiral, as shown at Fig. 72, we should find, on sending the current through the wire, that our bar would have three poles—*viz.*, a N. at each extremity and a S. at the centre; or, in other words, we should have produced “consecutive” S. poles in the centre of the bar. This, though absolutely fatal to the proper performance of a dynamo constructed of the two-pole single magnet type, is just what is wanted in those of classes *b* and *c* (see § 58), in which two or more F.M. cores are employed to magnetise a given pole-piece and produce therein the same polarity. To illustrate this point more clearly the reader is referred to Fig. 73, wherein A and B represent the pole-pieces of a Manchester type dynamo, in which it is requisite to

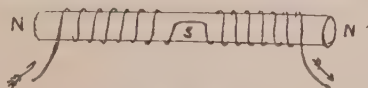


Fig. 72.

produce a pole of opposite polarity at A to that of B. To effect this it is evident that we must so wind the cores C and C' as to produce, say, N. poles at the upper extremity of each, and S. poles at their lower extremities, while the current is travelling in the same direction along

the wire. By starting the winding on the outside of the core *C* to the extreme left, and on the outside of core *C'* to the extreme right, and connecting the upper extremities as shown, we shall compass the end in view; since the current entering at *D* will produce a S. pole at the lower end of its F.M. core and a N. pole above, while as it travels in the opposite direction on entering the join at *D'* it will produce a N. pole at the top end of the core *C'*, and a S. pole at the bottom end of the said core; the central portions of each core being neutral, while the centres of the pole-pieces *A* and *B* will each partake strongly of the polarity of the ends of the cores to which they are respectively connected. It is

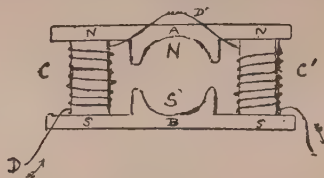


Fig. 73.

possible that the amateur may have wound both his cores in the same direction, and may consequently, on joining up the upper extremities of the wires, not get the desired consecutive poles; such a state of things is illustrated at Fig. 74, where the resulting polarity is shown. The effect of this is that the pole-pieces, instead of being actively magnetic, are absolutely neutral. Neither in this case is it necessary to disturb the winding of the field-magnets; all that is needful is to disconnect the wire at the junction *J*, and join the severed extremity *T* to the free end *B*, employing *B'* and *T'* as the new terminal wires.

§ 72. Machines with four cores and two pole-pieces are wound on

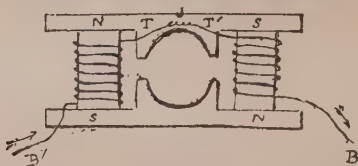


Fig. 74.

precisely similar lines; but as this multiplicity of cores may somewhat confuse the beginner, we subjoin a sketch of the proper mode of winding and connecting these (which must also have consecutive poles), and pointing out the possible mistakes in connecting, as well as the mode of remedying such if they have occurred. A moment's consideration will show that if there are four cores to two pole-pieces, the arrangement virtually consists of two horseshoe magnets, with their *like* poles connected together by the pole-pieces, as shown at Fig. 75. The student will have no difficulty in understanding that each horseshoe

must be wound as in Fig. 68, in order to produce the desired opposite polarity at the opposite extremities. And that in order that the polarity of the two poles of the magnets which touch the upper and lower



Fig. 75.

pole-pieces respectively should be of the same name, it is necessary that the winding of each magnet should be in opposite directions, as shown at Fig. 76. (We need not point out that whether the cores of the

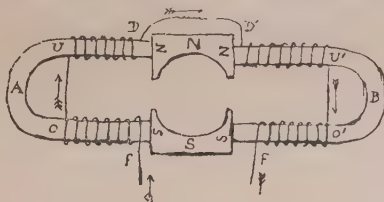


Fig. 76.

F.M.'s are continuous at A and B, or whether the limbs are connected together at these points by straight iron yokes, as in Figs. 69 and 70 A, there is no difference in the polarity set up.)

§ 73. Precisely similar in work, though somewhat differing in appearance, is the winding of the old A Gramme machine, of which Fig. 77 gives a good general idea. Here, as in Fig. 75, the winding

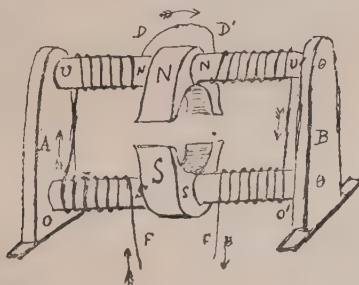


Fig. 77.

starts over the lower left-hand F.M. core and passes under the upper left-hand core, reversing its direction, and passing behind the upper right-hand F.M. core, emerging also from behind, and passing over in

front to the lower right-hand F.M. core. The mistakes in winding, which can possibly occur in the two forms described in §§ 72 and 73, are (1) those of winding the F.M. cores at A, so that the wire in passing from O to U, or O' to V', goes in front of both cores, or behind both cores, instead of in front of one and to the back of the other; or (2) that in passing from D to D at the upper pole-piece, or on leaving F F at the lower, one wire starts from the back, and the other from the front of the respective pole-pieces, instead of both starting from the back in the upper one and the front of the lower one, as they should do.

To remedy either of these defects, it will only be necessary to disconnect at A and D, and join the lower severed end of A to D, while connecting the upper severed end of A to D'.

§ 74. It does not follow, because the insulation of armature coils, of F.M. coils, and of brushes be perfect, and the direction of winding of the F.M. coils be correct, that the dynamo will necessarily work, or, if it work, that it shall work satisfactorily, because the relative amounts, gauges, and resistances of the wires employed for winding the armature and the F.M.'s may be disproportionate. It may also happen that the iron employed in the construction of the F.M.'s may be so hard to magnetise, as to require a very large amount of current to flow round the coils to magnetise it.

§ 75. It will be well to remember in this connection that, in order to magnetise to the full a piece of fairly good iron having a sectional area of one square inch, a current of about 14,000 ampères must flow round it.¹ We are not obliged to send the 14,000 ampères along *one* coil of wire to obtain this result. The same effect is produced if we cause the wire to make 14,000 convolutions round the iron core, and supply only 1 ampère. For this reason we generally speak of the "ampère-turns" employed in exciting an electro-magnet, in preference to specifying the number of ampères to be used. In other words, it is usually found that it is absolutely immaterial to the final magnetisation obtained in a given piece of iron whether we send 1,000 ampères through a single turn of wire (which, in this case, must be stout enough to carry the 1,000 ampères) coiled round the iron, or whether we send 1 ampère through a wire making 1,000 turns round the same piece of iron.

§ 76. Another point which it is of the highest importance to bear in mind in the construction of electro-magnets is that the effective magnetism set up in the iron is irrespective of the length of the core, but directly as the transverse sectional area of the core on which the coils are wound. Any extension of the pole-pieces will not increase the magnetism, but only modify the position of the points of greatest intensity. It is very rare that the F.M.'s of dynamos are magnetised to saturation; in practice it is found more economical to use larger masses of iron and less current to produce the desired result. For example, taking the little Siemens dynamo described in the first part of this book, in which the F.M. core is $\frac{1}{2}$ in. thick by 4 in. wide, or, in

¹ This is deduced from the author's own experiments.

other words, has a sectional area of $4 \times \frac{1}{2} = 2 \text{ sq. in.}$, it is found that with the winding therein given—namely, 280 turns on each limb = 560 turns altogether—a current of 4 ampères is sufficient to excite the field-magnets to the desired intensity; and this corresponds to $4 \times 560 = 2,240$ ampère turns, which is less than $\frac{1}{10}$ of the saturation limit.

§ 77. If, therefore, the insulation, etc., being found good, the machine should not work, or if, though working, it gives an output much smaller than it is calculated to do,¹ the student will do well to disconnect the F.M. wires entirely from the brushes, and couple them directly to a battery (having regard to coupling-up so as to magnetise in the same direction as the field magnets were originally magnetised) with an ammeter in circuit, and while things are in this position to drive the dynamo at the normal speed, increasing or diminishing the battery power until the dynamo gives the desired output at the speed decided upon. Then, by reading off the number of ampères required to produce the magnetic field of the necessary intensity, it is easy to calculate, knowing the output of the armature at *that* given speed, and in *that* magnetic field, to alter the winding of the F.M.'s, so as to get the requisite number of ampère turns. Very often, especially with small machines (in which badly-annealed castings are used), it will be found sufficient to put the wires of the field-magnets in *parallel*, instead of in *series*. (To connect a pair of magnet limbs in parallel, all that is necessary is to sever the connection between the wire that connects the two limbs, and then join the severed end of the *right-hand* limb wire to the starting wire of the *left-hand* limb, and *vice versâ*.) This reduces the resistance of the F.M. winding to $\frac{1}{4}$, which is equivalent to allowing four times the amount of current to flow round them. Of course, a dynamo so treated cannot be (except in the case of a series or compound-wound machine) an economical machine, because so much more current will be wasted to excite the F.M.'s. But it often happens that a machine which, through bad or dirty fitting at the yokes, does not magnetise up readily when first put together and tested, will suddenly start and take a magnetic "set" when the powerful current admitted round its coils by having them placed in parallel is allowed to flow; in which case it is frequently possible to reconnect the wires as at first without lowering to any appreciable extent the output of the machine.

§ 78. As a little guide to the student, the following table of the quantities and gauges of wire to be used with dynamos of three types usually constructed by amateurs, along with the sectional area of the iron cores of the field-magnets, in inches, as also the length of the winding space left for wire, is subjoined.

It will be noticed that owing to the poorer magnetic contact, the inferior fitting, and the necessarily harder castings which obtain in very small dynamos, resistance of the F.M. winding has to be kept very low in the shunt-wound machines, so as to allow a large current to pass, and here *apparently* the law relating to *ampère-turns* (§ 75) does not

¹ That is to say, less than 1 volt for each yard of *active wire* on the armature, when running at a peripheral velocity of 1,250 ft. per minute.

TABLE OF THE PROPORTIONS OBSERVED BETWEEN THE ARMATURES AND FIELD MAGNETS OF DYNAMOS.

Type of Armature.	Siemens H. ¹				Ring. ²				Drum. ³			
	1	2	3	5	3	5	6	10	30	5	6	10
Output in ampères.....	12	15	25	35	25	35	55	55	30	35	55	30
" " volts.....	5	10	20	50	20	50	100	200	600	50	100	55
Output in candle power.....	1"	1 1/2"	1 3/4"	2 1/4"	3 3/8"	4"	5"	6"	6"	2 1/2"	3"	200
Armature diameter.....	1 1/4"	3 1/2"	3 3/4"	4"	2"	2"	3"	6"	8"	4 1/2"	6"	4"
" length.....	1 3/4"	3 1/2"	3 3/4"	4"	2"	2"	3"	6"	8"	4 1/2"	6"	8"
" gauge of wire on.....	24	20	30	18	22	20	20	16	12	20	18	16
" yards of wire on.....	20	20	30	45	80	160	280	144	96	80	112	120
" weight of wire on.....	2 oz.	4 oz.	6 oz.	1 lb.	11 oz.	2 lb.	3 1/2 lb.	6 lb.	12 lb.	11 lb.	2 1/2 lb.	5 lb.
" resistance in ohms.....	0.6	0.5	0.7	0.67	0.7	1	1.75	0.3	.075	0.5	0.6	0.25
Field Magnets, section in square inches..	1 1/2	1 3/4	2 1/4	2 3/4	1 1/2	1 1/2	2	2 1/2	3 1/2	4 1/2	7 1/2	10
" winding space, inches.....	4	8	8	9	7	8	12	14	20	6	8	9
" F.M.'s, gauge of wire on.....	20	16	16	14	18	16	16	12	8	16	14	12
" yards of wire on.....	40	48	60	90	45	96	144	120	56	48	75	64
" weight of wire in lbs.....	1 1/2	2	2 1/2	6	1	4	5	15	14	2	5	8
" resistance of wire in ohms	1	0.38	0.42	0.46	0.66	0.76	1.18	0.37	0.065	0.38	0.37	0.19
" ratio of resist. to armature	1	3/4	3/4	3/4	9/8	3/2	3/2	3/2	7/8	3/2	3/2	3/2
F.M.'s, gauge of wire on.....	24	20	20	20	22	20	20	18	18	20	20	18
" yards of wire on.....	120	160	240	400	240	640	960	1890	2250	400	480	1755
" weight of wire on, in lbs...	3 3/4	2	3	5	2	8	12	42	50	5	6	39
" resistance of wire in ohms	7	4	6	10	10	16.7	25	30	33.1	10	13	25
" ratio of resist. to armature	7	8	9	15	15	16.7	15	100	440	20	20	100

¹ Running in single magnets, poles downwards.² Running in Gramme or Manchester fields.³ Running in single magnets, over-type.

hold good. In other words, it would appear that in very small machines it requires a larger number of *ampères*, in contra-distinction to mere ampère-turns, to overcome the reluctance of these inferior magnetic circuits. When, however, we come to machines of a certain size, say 1 unit (1,000 watts) output and upwards, Sir Wm. Thomson's rule for the ratios gives perfectly satisfactory results. This rule is :—

For series machines	{	Armature resistance . . .	1
		Field-magnet resistance . . .	$\frac{2}{3}$
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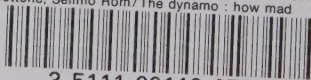
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